Enhanced System Planning Project

C4NET | ESP Enhanced System Planning

C4NET Project Overview

Technical modelling of electrification of heating (and cooling) profiles

Work Package 1.1

January 2025

C4NET

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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.*

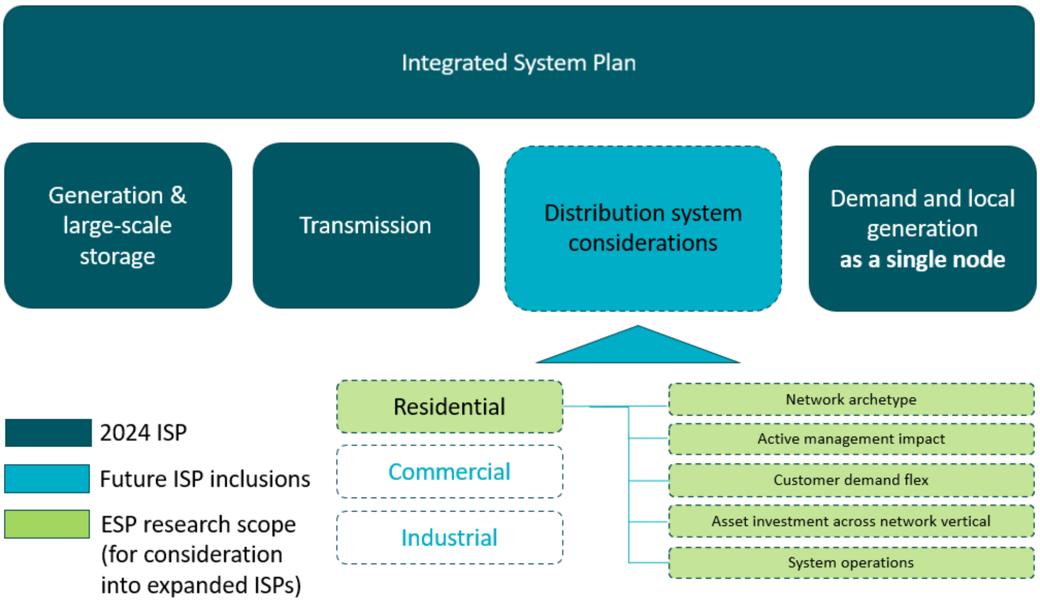

Figure 1 – Relationship between ISP and ESP

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.
- **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, the University of Melbourne undertook an independent research project: *Technical modelling of electrification of heating (and cooling) profiles*, with the goal of developing a modelling tool to understand the impacts of the electrification of heating, cooling and domestic hot water on residential demand profiles.

This report is designed to guide stakeholders in their understanding of how the research and tool developed can be used to assess the demand profile impacts that are quantified 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 *Technical modelling of electrification of heating (and cooling) profiles* research project sought to develop a modelling framework and tool to inform a baseline of understanding of the impact of electrifying the energy system. This is illustrated as a key feature of the base case in *Figure 2* below.

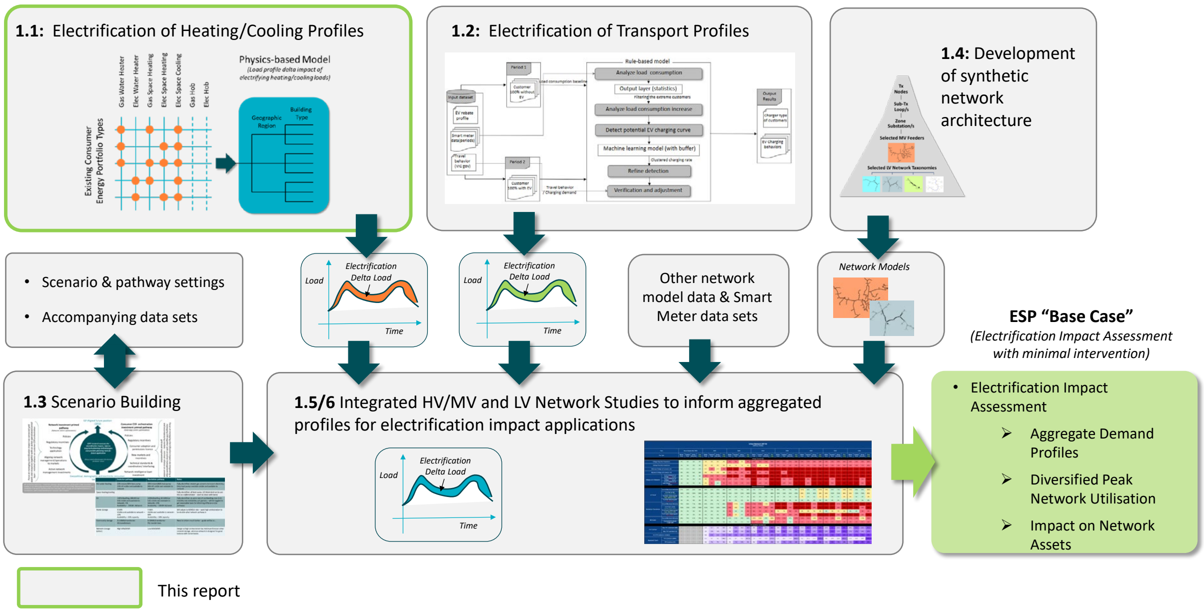

Figure 2 – Relationship between this research project and other projects in Work Package 1

Transitioning domestic gas loads to electrification is a key lever to achieve decarbonisation objectives and given the scale of domestic gas use, particularly in Victoria, this is considered material for electricity network infrastructure planning.

The research project has developed a modelling framework with the capability to evaluate the impacts of substituting gas with electricity in domestic installations, and the resultant impact on electricity demand to enable the network to be planned accordingly. This was done through a development of a highly accessible tool and has been built using a granular bottom-up approach to model the impacts for a given set of inputs that can be varied by the user.

The approach taken delivers the following:

- a modelling framework that uses individual building-level models including representative building types, regional climate zones, appliance technologies (space heating/cooling and domestic hot water (DHW)), occupant energy behaviours and seasonal daily demand curves.
- a tool with a user interface in the form of an Excel input file which allows the user to aggregate different combinations of building models.

- the ability to estimate impact on aggregated demand at a diversified level using available data for housing lots in greenfield residential developments, and with additional research and/or estimation of model parameters the aggregated demand for existing residential homes.
- an aggregated demand at a diversified level can then provide input to determine the distribution substation infrastructure required on site to service the needs of the greenfield developments and the cost to provide it, as well as the infrastructure upgrade requirements for existing residential homes.

In addition, the research project has also contributed the following key insight. The model demonstrates that network tariffs consisting of “off-peak” and “solar soaking” provisions could moderate the increase in electricity peak demand.

The model outputs will be used to assess potential impact on aggregated demand of residential properties through the subsequent project in work package one: *Integrated MV-LV network studies to inform aggregated profiles for electrification impact applications*.

3. Research methodology and approach

A top-down approach can rapidly inform the annualised and seasonal energy impact of electrification of domestic gas 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)[3] at each level of distribution network asset from transmission connection through to customer meter.

Further consideration of broader concurrent changes on the system such as decentralisation of generation (solar PV in particular), energy storage, population and housing changes, consumer activity and electrification of transport necessitate a means of granular assessment in temporal and locational aspects. In doing so, network planning can be considered from a whole-of-system impact, including network operation, consumer, regulatory and market structure considerations. These impacts are anticipated to be most material in areas of high residential reticulated gas use, such as Victoria, South Australia and southern NSW.

3.1 Approach

A bottom-up approach for the electrification of heating and cooling and hot water systems needs details of the devices used, when they are used and mechanisms to scale with changing population, dwelling mix and location. To achieve this, the modelling framework uses individual building-level models including:

- representative buildings which were determined based on selected attributes such as building type, household size (occupants), thermal characteristics and energy efficiency levels;
- location, where four locations for those buildings were chosen to represent the typical climate zones found in Victoria – Ballarat, Melbourne, Shepparton and Traralgon;
- electric heat pump (EHP) space heating/cooling technology and domestic hot water technologies currently available;
- occupants' energy behaviours, including temperature setpoints, activation strategy (when the system is turned on) and the effect of restrictive/specific tariffs (off-peak and solar soaking); and
- 30-minute demand profiles over a 24-hour period for representative day types including Winter Peak, Winter Average, Summer Peak, Summer Average and Shoulder. These day types were chosen considering the high seasonality (weather sensitivity) of the household thermal demand.

[3] 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.

3.2 Inclusions, exemptions and limitations

The researcher's approach considered:

- gas substitution in space heating/cooling and domestic hot water are two residential energy services that are likely to contribute to significant increase in peak electricity demand. C4NET notes this in turn supports informing the impact on energy delivered;
- space heating/cooling, in particular space heating, is likely to switch over to electric heat pump technology.
- replacement technologies for gas domestic hot water (DHW) currently consist of electricity based instantaneous flow and those incorporating a storage tank.
- customer activation strategy such as the device operating parameters that are customer controlled like what time the system is turned on each day. For example, the base activation strategy used in the report incorporates setpoint for space heating that is based on other research work;
- modelling energy consumption to be based on the use of a building-level thermal model with attributes including building type (detached house, semi-detached house, flat/apartment), household size, thermal characteristics (thermal insulation level) and energy efficiency levels
- modelling two initiatives that impact on customer activation strategy:
    - for space heating/cooling the "Delayed" activation strategy (off-peak)[4] according to which the heating/cooling system is not turned on in the morning but only in the afternoon/evening when occupants come back home; and
    - and for DHW the "off-peak controlled load" and "solar soaking" modes[5] have been simulated, which assume that water heaters are operated under restricted/specific tariffs or only operate within a specified time window to maximise the consumption from the increasingly widespread rooftop solar PV systems.

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

- only heat pump technologies have been modelled, and within that only certain size systems used. In practice, there will be a wide variety of systems used, and heat pump alternatives are likely to be developed within the period of intended outlook (through to 2054) given it is so far off. The underlying approach should be consistent regardless and can be updated with more contemporary data at any time. Users should always be cognisant of the most appropriate devices to be modelled and subsequent limitations of its ability to inform.

[4] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 3 (v), page 25

[5] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 3 (v), page 25

- gas for cooking has been excluded due to its immateriality relative to hot water and heating and cooling.
- while residences tend to have a single hot water unit each, it is a lot less binary with heating and cooling. Residences may have one large system for the whole house or may have a series of smaller units. Further to this, the granularity of the base case or starting point from which any change is to be measured is relatively poorly informed. For example, houses may already have some electric cooling in place and a gas heater but consolidate when electrifying the gas component. Any limitation due to this is expected to diminish over time as conversion trends become more predictable and better informed by empirical data.
- Only residential dwellings are considered. Electrification in the Commercial and Industrial sectors will also affect the demand profiles particularly the aggregate impact on the sub-transmission, zone substation and high voltage feeder assets. The impact is excluded from this research project.

3.3 Base assumptions

The specific daily outdoor temperature profiles for each representative day type were obtained by analysing 10 years (2014-2023) worth of temperature data with 1 min resolution for each location. The profiles are therefore based on historic temperature observations, rather than forecast[6], and do not take into account of the increasingly extremes in temperature caused by climate change.

To generate the after-diversity average customer-level demand profile for each energy service, multiple buildings are simulated. For this purpose, a building number of 300 was selected for the simulations, as a trade-off between computational burden and impact on the peak demand[7].

For the feed-in water temperature to generate the domestic hot water demand profiles, this is assumed to vary across season, and it is assumed to be constant throughout the day and the same across all locations[8].

3.4 Researcher model

A specific tool[9] was developed, coded in a software language called Python, which allows combining the different average customer level demand profiles for each energy service, i.e., space

[6] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 3 a) (iii), page 20
[7] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 3, page 18
[8] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 3 a) (iii), page 23
[9] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 4, page 25

heating/cooling and DHW, given the total number of buildings in the area under analysis and the proportion of building with specific attributes.

The tool has a user interface in the form of an Excel input file. This allows the user to aggregate different combinations of building models to determine the resultant impact on electricity assets and infrastructure.

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

Victorian DNSPs produce 10-year forward-looking maximum demand forecasts for their electricity networks. The demand forecast forms the basis of the expenditure forecast for network expansion and augmentation. While forecast of peak demand always carries a degree of uncertainty, many influencing factors (such as maximum ambient temperature, economic growth, dwelling increase) are well understood and can generally be inferred from recent trends. Policy decisions with regards to domestic gas substitution, however, represent a step change in electrical energy consumption that has no precedent and hence a higher degree of uncertainty which would benefit DNSPs exploring more fully, such as:

- What are likely to be the gas appliances that will be switched over to electrical appliances in a residential premises?
- When the switch occurs, what are the likely technologies to be deployed?
- What consumer usage patterns/activation strategies will emerge?
- What are the energy consumption profiles of the new electrical appliances based on customer activation strategy in different seasons?
- What can be done to encourage a favourable change in customer activation strategy?

The research undertaken has sought to provide a foundational building block for the ESP to inform the impact of uptake rates on demand profiles and inform the DNSP of these parameters, and the model developed can further support DNSP analysis of their own data. Shown below in *Figure 3* is an example of the possible demand profile for space heating during a winter peak day for different building types with three bedrooms and “new” insulation level in Melbourne[10]. Because of the different geometry and construction materials’ thermal properties, these profiles differ not only in terms of magnitude of peaks but also when these peaks occur and for how long they are sustained. The inputs to the model are adjustable by the user to inform different situations.

[10] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 5 (a), page 30

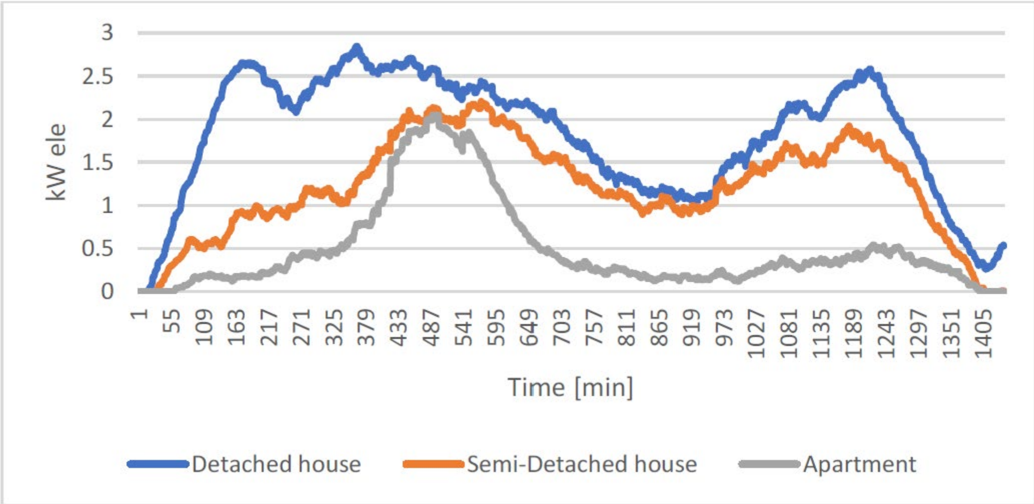

Figure 3 - Demand profile of space heating during a winter peak day for different building types with three bedrooms and “new” insulation level in Melbourne

It is recommended that DNSPs consider the use of this physics-based, bottom-up model to forecast the native impact (i.e. before any demand management or non-network solutions) on demand at a diversified level of a residential property due to electrification of space heating/cooling and domestic hot water energy services.

4.1.1 Using the researcher’s model

Using the model developed by the researchers, to arrive at the forecasted increase in electricity peak demand based on gas substitution in the two residential energy services, DNSPs will need to specify parameters in the tabs “Inputs”, “Proportions space conditioning” and “Proportions DHW”[11]:

	A	B	C	D
1	**Parameter**	**Selection**	**Notes**	**Value**
2	Location	Ballarat		1
3	Day type	Winter Peak		1
4	Energy services	Space conditioning		1
5	Total number of buildings	100	Value must be greater than 0	100
6	Energy vector for space heating	Electricity	[1]	0
7	Energy vector for domestic hot water	Gas	[2]	1
8	Proportion LATE space conditioning activation strategy (%)	100%		1

Figure 4. Excel inputs interface to the Python tool for the aggregated profiles

[11] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 4 (a) (i), page 28

Building type	Detached house	Semi-detached house	Apartment	Check
%	21.00%	19.00%	60.00%	OK

Household size (%)	1 occupant	2 occupants	3 occupants	4 occupants	Check
Detached house	25%	35%	30%	10%	OK
Semi-detached house	25%	25%	25%	25%	OK
Apartment	50%	25%	25%	0%	OK

Building insulation level (%)	Efficient	New	Modern	Old	Check
Detached house	10%	27%	13%	50%	OK
Semi-detached house	20%	40%	10%	30%	OK
Apartment	50%	20%	20%	10%	OK

Figure 5. Example of proportion tables to generate space conditioning aggregated profiles

Household size	1 occupant	2 occupants	3 occupants	4 occupants	Check
%	25%	35%	30%	10%	OK

DHW technology	EHP water heater	Resistive storage water heater	Check
1 occupant	30%	70%	OK
2 occupants	23%	77%	OK
3 occupants	47%	53%	OK
4 occupants	30%	70%	OK

DHW activation stategy	Temperature controlled	Off-peak controlled load	Solar soaking	Check
1 occupant	20%	30%	50%	OK
2 occupants	50%	10%	40%	OK
3 occupants	40%	15%	45%	OK
4 occupants	10%	50%	40%	OK

Figure 6. Example of proportion tables required to generate DHW aggregated profiles

An example of the aggregate demand profiles on a winter average day for 100 modern 2-bedroom residential properties in Melbourne, with different proportion of building types (detached house, semi-detached house` and apartment), is shown in *Figure 7* below[12]:

Case	Detached house	Semi-detached	Apartment
A	100%	0%	0%
B	75%	25%	0%
C	25%	50%	25%
D	20%	40%	40%

[12] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 5 (c), page 38

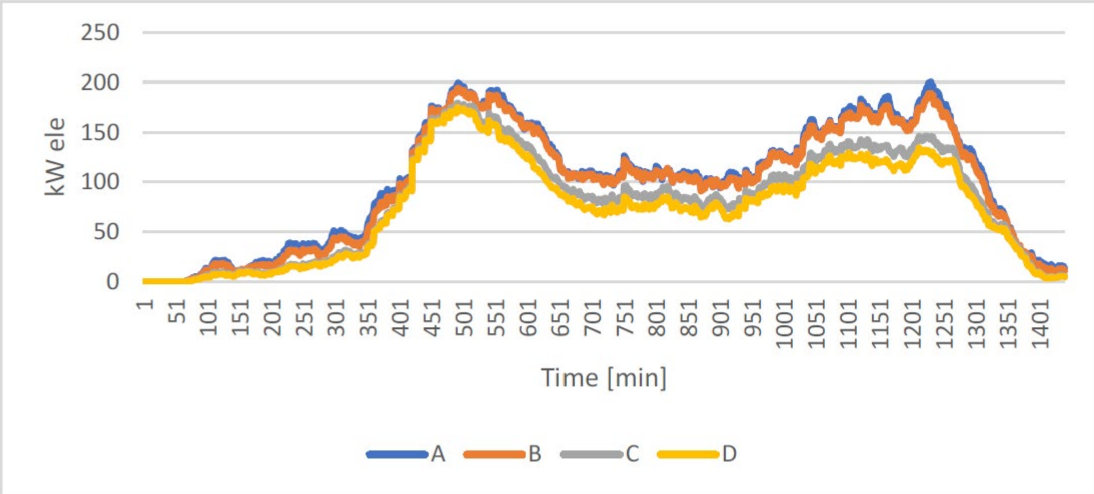

Figure 7. Aggregated demand profile for space heating on a Winter Average day for a two-bedrooms modern buildings in Melbourne, with different building types proportions

4.1.2 Model insights for DNSPs

For greenfield residential developments e.g. those by large developers, the model input parameters are reasonably known, and the model can be used to estimate the demand profile for electric heating and domestic hot water at a diversified level of each housing lot. The aggregated demand profile can then provide input to determine the distribution substation infrastructure required on site to service the needs of the developments.

For gas substitution occurring in existing residential homes, the input parameters required by the model are not necessarily known. DNSPs will have to make reasonable estimates or carry out additional research to estimate the parameters.

The model demonstrates that network tariffs consisting of “off-peak” and “solar soaking” provisions could moderate the increase in electricity peak demand. This can be considered by DNSPs in their tariff design as part of the broader objective of AEMC’s reform to assist customer participation in the energy market. Opportunities currently exist for DNSPs to modify approaches to tariffs and price signals with the electrification of appliance products, such as instantaneous electric hot water, heat pumps with daytime heating etc. These opportunities should be taken to provide support for the energy system and to further ensure the transition is straight forward for consumers. An example of the demand profiles for DHW under different activation strategies is shown in *Figure 8* below, indicating a reduction in the evening peak (by about 0.3kW) when customer responds to either solar soaking or off-peak provision[13]:

[13] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 5 (b), page 37

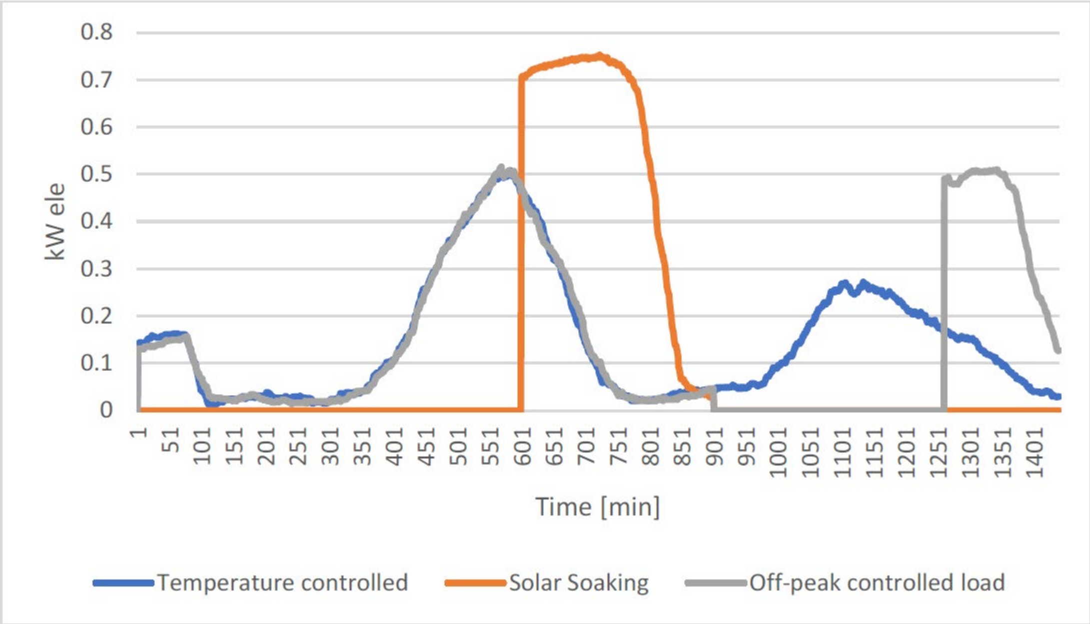

Figure 8. Average building-level DHW demand profile for a three people household in Ballarat on a Winter Peak day supplied by an EHP water heater under different operating strategies

The bottom-up modelling framework and tool developed by the project is most useful for determining the electricity demand impact on the local infrastructure caused by the electrification of residential heating (and cooling) and DHW. While the tool is foundational and addresses the residential demand well, the demand impact on non-residential parts of the network will need to take into account the change in commercial/industrial load demands and their diversity. In this regard further research work is required to understand the impact of electrification from commercial/industry loads.

4.2 AEMO

AEMO currently applies a top-down model to forecast the electricity demand at the system level and at the transmission connection points to the distribution networks. The AEMO model broadly takes into account demand changes caused by electrification. The bottom-up model developed by this project may provide additional insight for AEMO with regard to the impact of tariff policies and technology impacts. It may also further assist in the reconciliation of the AEMO top-down forecast with DNSP's bottom-up forecasts at the transmission connection points taking into account of regional and dwelling differences.

4.3 Policy makers

The model demonstrates that network tariffs such as those consisting of “off-peak” and “solar soaking” provisions could moderate the increase in electricity peak demand when gas substitution occurs. Consumer uptake of time-of-use (TOU) tariffs, however, has not been high to date and the effectiveness of them as a mechanism alone or in combination with other mechanisms to shift demand needs to be informed.

Policy makers can play a facilitating role in introducing a range of mechanisms or incentives that may improve the move towards electrification noting that consumption adaptation needs to balance the value for both the individual and communal system benefits, in a manner that avoids complexity for households:

(1) Standards – enhance appliance standards and quality to ensure appliances support the benefits of electrification

(2) Incentives:

  a. provide ongoing incentives for existing gas consumers to replace gas appliances with electric appliances

  b. reduce the cost barrier of converting a site

  c. consider linking existing incentives – e.g. an incentive for solar PV could include a requirement to be linked to an electric hot water storage system with its heating cycle aligned to solar generation.

(3) Tariffs – To a limited degree, consumer behaviour and choices will be influenced by the price they pay. If seeking to shift usage time to avoid network congestion, then tariff structures should be assessed as to how well aligned they are to achieve this. It is noted that:

  a. network tariff structures are only a component of the consumer bill, it is the retail tariff and price that is relevant to the consumer

  b. the bulk of consumers prefer simplicity over complexity with utility products as few are deeply engaged in considering their purchase and usage of electricity. For any pricing incentive to work it would need to be easily understood and highly visible.

  c. Remote and third-party operation of hot water systems has been broadly accepted over many decades as it can be achieved while meeting consumer's needs (including the ability to override when desired). There are differences in the heating cycles of heat pumps that are somewhat more restrictive than resistance heaters, however in the main they are still well placed for remote/automated heating cycles to align with either solar generation or to avoid network congestion.

  d. It is plausible that pre-heating/cooling of houses could be used to shift usage times, or remote or third-party control of thermostat could moderate electricity use in peak events. This would be dependent on the level of acceptance of consumers of such measures and the relative incentive to do so, and there is little evidence to support this to date.

(4) Disincentives or limitations on the sale of new gas appliances

(5) Awareness - raise awareness of consumers to the incentives/tariffs/automation opportunities that are designed to reduce the overall costs to support the move to electrification

The project has also identified that the Coefficient of Performance for air-sourced Electric Heat Pump (EHP) is very dependent on indoor and outdoor temperature[14]. Proper sizing of the EHP at the design stage is important to make sure that, given its performance characteristics, the heating unit can deliver the required heat demand in design conditions. It does appear that policy makers can assist consumer choice in EHP by providing educational information.

4.4 Consumer

The report highlights the likelihood that the rating of the heat pumps replacing gas furnaces will be higher than the incumbent asset[15], and consumer awareness of this may help with their procurement decisions.

The time profile of the change in indoor temperature in a EHP system (responding to a step change) will be different to that of a gas system, and this may impact consumer experiences.

With the bulk of consumers on gas storage hot water systems where reticulated gas is available, as they transition to electricity systems they can consider the operation of these systems in a more integrated manner for their overall energy purchase. For example, where electric storage systems are installed, the consumer will have choice about when to heat their system, including consideration for any solar PV generated on site, other site storage options, their preferred retail tariff deal and their lifestyle needs.

4.5 Research

The physics-based, bottom-up model that has been developed will be of value to the local and international research communities.

To validate the model a population of known sites could be used to develop empirical evidence. A large enough sample would need to be identified to cover the diversification of the aggregated profiles typically achieved observed at distribution transformer level. Regions such as Victoria where there is ubiquitous smart meter adoption and complementary electrification will be ideally suited for this validation exercise.

Further research opportunities include:

(1) As Victorian buildings' space heating is most commonly supplied by gas, further validation of the model could be conducted by comparing the typical gas consumption by season (e.g., in Winter)

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[14] WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 2 (b) (i), page 10

WP1.1 Technical modelling of electrification of heating (and cooling) profiles Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024, Section 2 (b) (i), page 11 by household size, considering appropriate weighing factors to account for “peak” as well as “average” days. This would require more detailed information on the breakdown by energy service, i.e., space heating, DHW and cooking, buildings’ thermal properties/size as well as outdoor environment conditions these refer to. The same approach could be adopted for DHW.

(2) The electricity demand profiles considering EHP as space heating/cooling technologies have been obtained considering the performance parameters available from only one manufacturer. Additional information from real-world tests on EHP performance from multiple manufacturers would be ideal to better inform the modelling of the EHP operation.

(3) The modelling assumes that EHPs will be used for space heating/cooling. The modelling approach can be adapted when other technologies are installed.

(4) As there are already all-electric houses built, validation of the model against these all-electric houses will be most useful if the home details are known.

Appendix One

Researcher profile

Conducted by: The University of Melbourne

Lead Researcher: Prof Pierluigi Mancarella

Research Team: Antonella De Corato, Sleiman Mhanna, Sebastian Puschel

Department of Electrical and Electronic Engineering

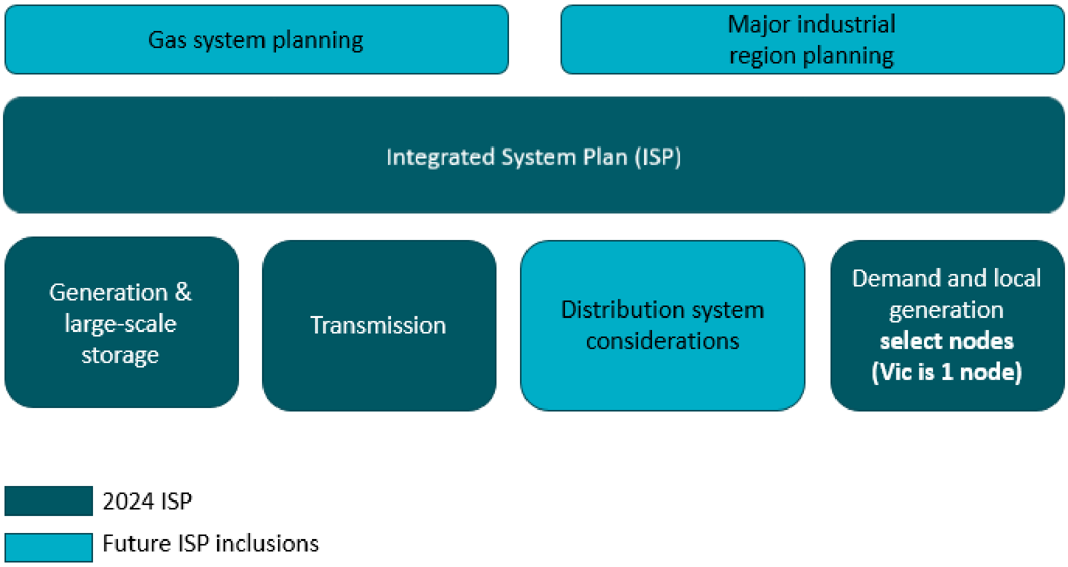
About C4NET

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.

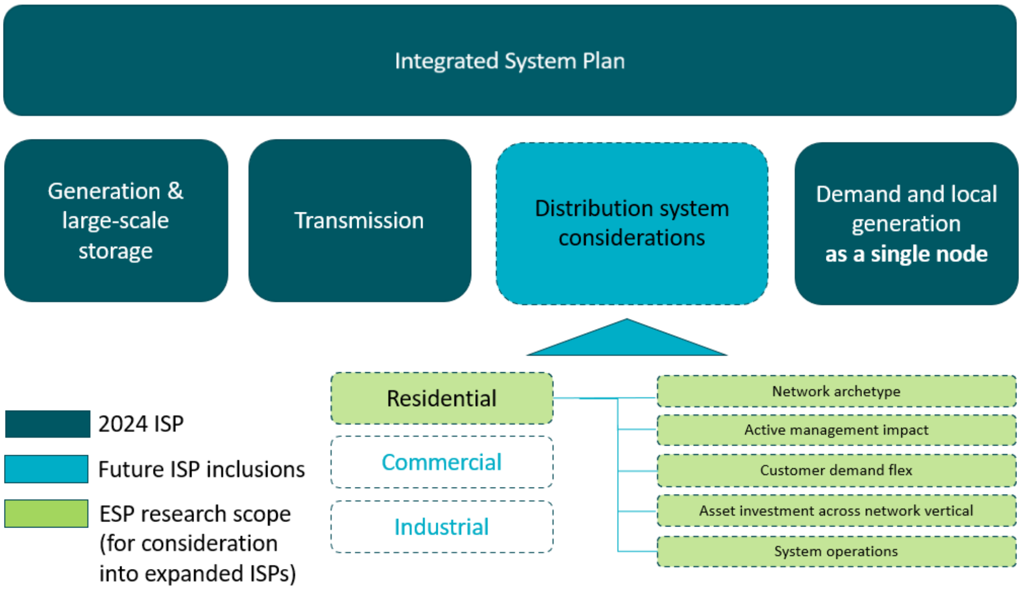
Appendix Two – Bigger picture integration with the ISP

Shift towards whole of system planning



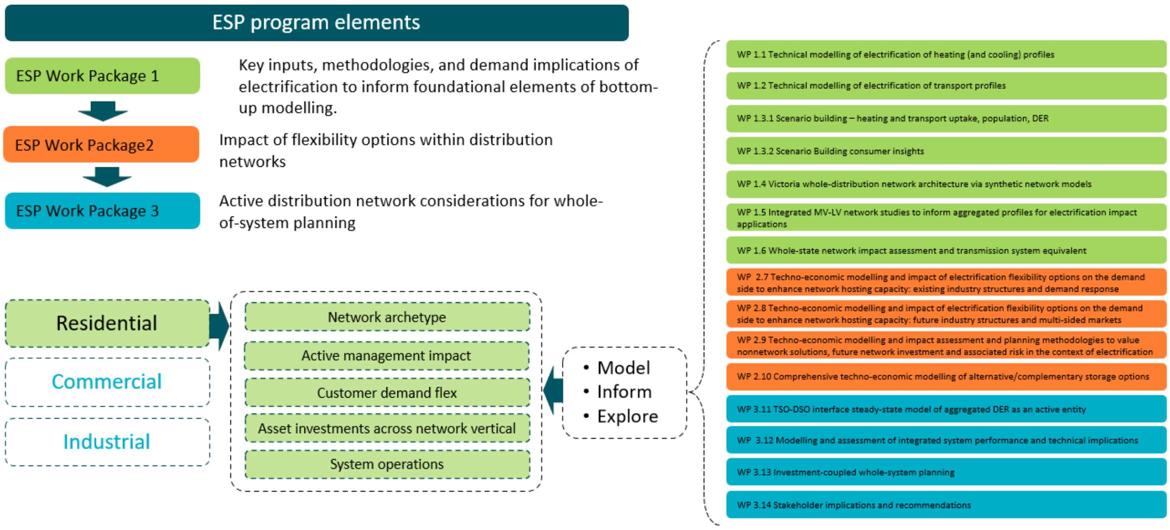
The Energy and Climate Change Ministerial Council (ECMC) accepted the recommendations of the review of the ISP which target transformation of the energy system as a whole, with particular reference to gas system planning, major industrial region planning and distribution systems.

Distribution system components of whole of system planning

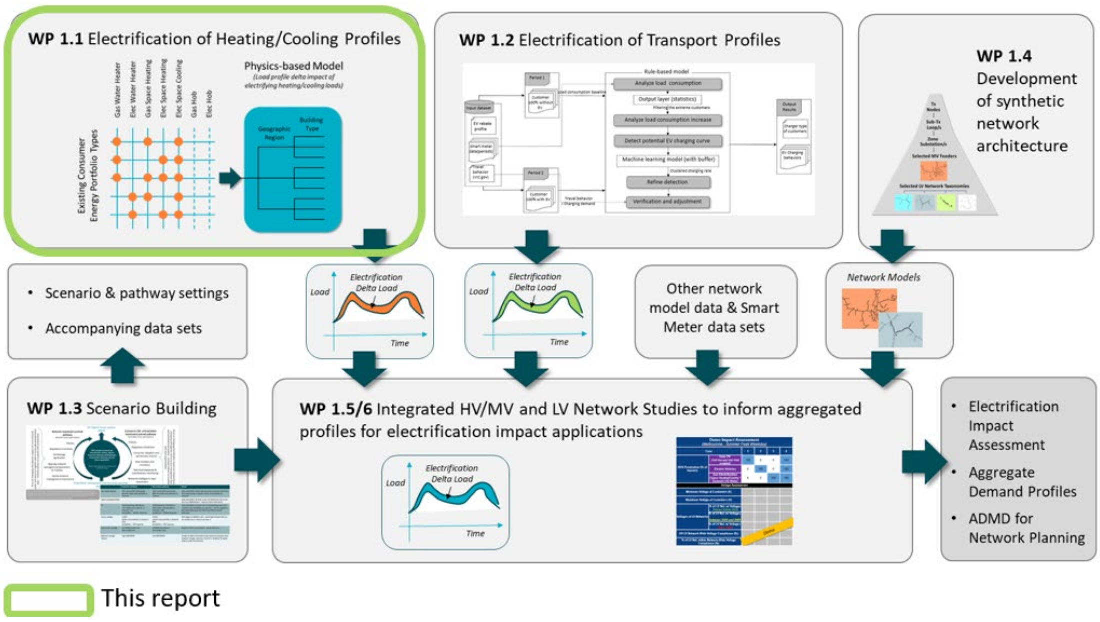


The ESP was scoped to be deliverable with the resources and time at hand to inform feasibility of broader application. It focussed on the more complex areas around residential and low voltage assets of the distribution system, with an application across Victorian networks with methodologies applicable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

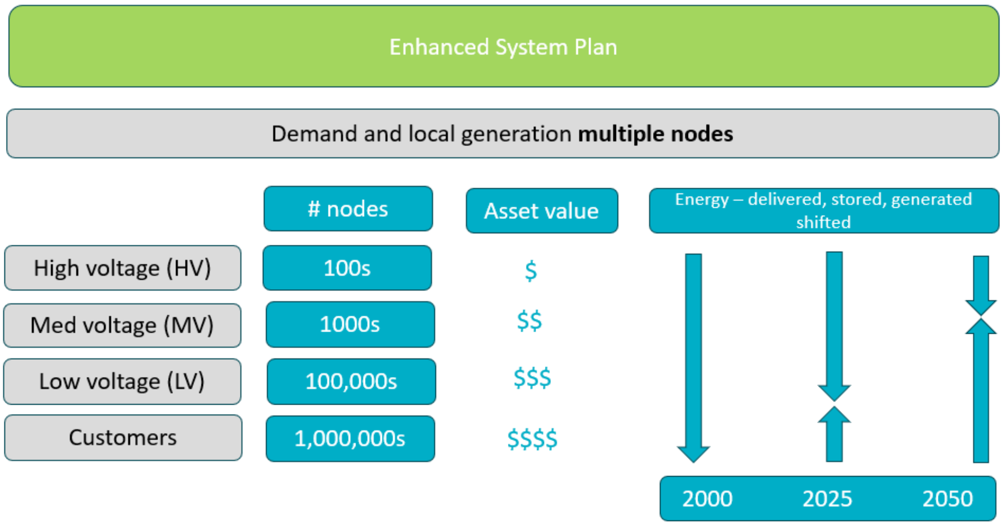
ESP alignment with distribution system components of whole of system planning



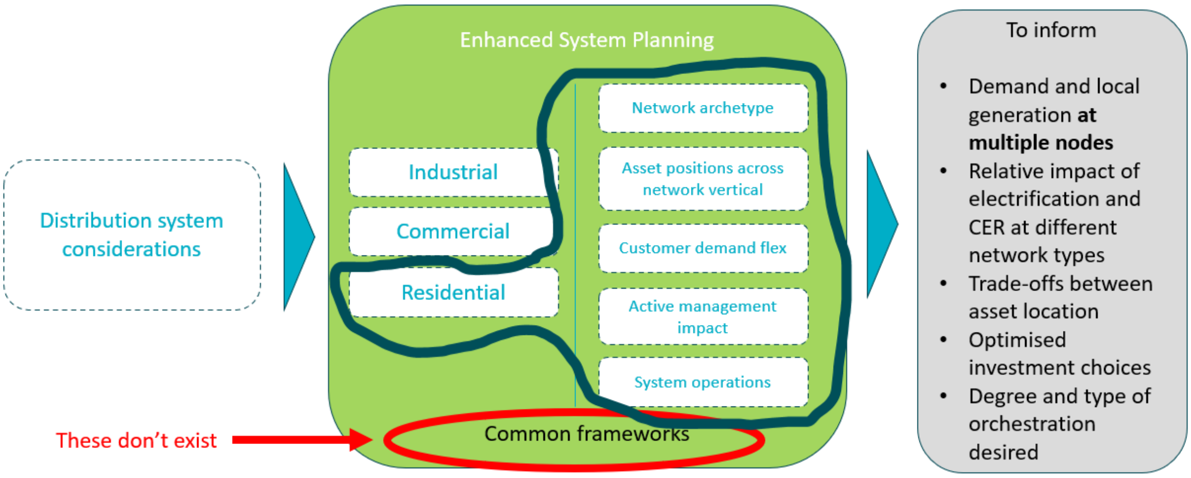
The 'base case' for residential electrification impact assessment, the flex options and relativity to other investment options



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