APGA Study

Supply chain analysis methodology for total customer cost

December 2022

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1 Introduction

The challenge of maintaining global warming well below 2 degrees is a near insurmountable challenge, but a challenge we must face as a nation and a global community as a whole. While many recognise that we need to use all tools at our disposal to achieve this end, some focus upon the notion that the single set of tools within the electrification toolchest are the only tools required to solve this challenge. This assertion is generally founded on single points of data – the low-cost of variable renewable electricity; the high cost of renewable gas production; the high efficiency of heat pumps; and more energy efficient supply chains – however few studies consider like-for-like comparisons of renewable energy supply chains right the way from energy production through to the customer cost of heat or other outcome provided by the energy being used.

This study proposes a supply chain analysis methodology which considers key components of the energy supply chain alongside key factors relating to the appliances required to achieve the quantity and quality of heat required by a customer. In order to demonstrate this methodology, the study considers the appliances required to provide heat in freestanding Victorian households which use gas for heating today. Application of the methodology is demonstrated by considering how each of these variables impact customer cost of heat in the home in FY2020-21, and how this may change in a net zero energy future.

To determine the total customer cost, the method considers how each component of the energy supply chain works together with each appliance factor to provide heat for energy customers. This approach recognises that the most efficient solution may not necessarily be the most cost-effective solution. A cost-effective solution is only achieved when the entire supply chain delivers customer cost outcomes which are equal to or less than that of the customers next viable alternative to achieving the quantity and quality of heat they seek.

This study considers the cost of providing the desired heating outcome at the customers desired quantum, rather than the cost of the first or last unit of heat energy provided energy. This is important as energy costs can become obscured when only the first or last unit of energy is costed. To this end, this study references the Frontier Economics study *Cost of switching from gas to electric appliances in the home* which considers the cost of appliances delivering the same heat to a home as existing gas appliances do today.

Outcomes from the application of the methodology are further explored through the application of Sensitivity Analysis Scenarios. These consider variations in the data used within the core study scenarios based upon five reasonable future scenarios relevant to the customer cost of heat in the home. Both the core dataset and its sensitivities are considered in the discussion section of the study, and recommendations are produced for policy makers.

It is hoped that this method proves useful in considering the true customer cost of competing energy supply chain alternatives, and that this in turn leads to more effective energy decarbonisation policy enabling the least cost, most rapid decarbonisation pathway for Australian energy customers.

2 Supply chain analysis methodology

The supply chain analysis methodology combines real or modelled retail energy price ranges with ranges for appliance cost and efficiency.

Cost = (Retail Energy Cost x Appliance Efficiency) + (Annualised Appliance Cost / Annual Energy Use)

While data exists on actual retail energy costs, future retail energy costs are uncertain. These can be modelled using a relevant breakdown of retail energy costs which allows the user to consider the various changes which will likely occur to change retail energy prices in the future. This study references the average retail bill cost breakdown provided by the Australian Energy Regulator (AER), however other breakdowns can be used.

Each component of AER energy bill breakdown can be scaled to model future retail energy prices based on data relevant to each component of the AER bill breakdown following the following formula.

$$\textit{Retail Energy Cost}_{\textit{net zero}} = \sum(\textit{Retail Energy Component Cost}_{\textit{FY2020-21}} * \textit{Net Zero Energy Scalar})$$

Simple as the total customer cost methodology may be, the real rigor of this method comes from the rigor applied to determining realistic ranges for appliance efficiency, appliance cost and retail energy cost, and in turn, for each component of whichever retail energy cost model is applied to this methodology.

2.1 Supply chain analysis methodology application within this study

This study applied the supply chain analysis methodology to the decarbonisation of gas use in a freestanding home in Victoria. As such, the AER bill cost breakdown data for Victoria will be used to model retail energy prices, accompanied by household and appliance gas use data for Victoria. Gas appliance cost data from a report which considers appliance costs to achieve the same level of heat provided by gas appliances in freestanding Victorian homes today.

The results of this analysis will be a model of the customer cost per unit of heat energy used in the home in the energy units kilowatt hours thermal (kWht). The quantity of thermal energy exiting appliances in kWht is a direct representation of the quantity of heat which households experience when using heaters, hot water systems or stoves. This will be applied to the electricity and gas supply chains of FY2020-21 as well as future net zero electricity and gas supply chains based on data from the literature review section of this study. A series of sensitivities on this data will also be considered in order to understand how different circumstances may impact future household energy costs.

3 Application of supply chain analysis methodology

It is possible to apply the supply chain analysis method to the total customer cost of heat in the home as delivered by various energy supply pathways, provided sufficient data is available to accurately model retail energy costs, appliance costs and appliance efficiency. The necessary data to consider the total customer cost of heat in the home in FY2020-21 (Section 3.2) and net zero heat in the home via net zero electricity and net zero gas pathways (Section 3.2.5) has been collated within the Literature review section below (Section 3.1)

3.1 Literature review

Supply chain analysis of the customer cost of heat in the home is dependent on data pertaining to current and future retail energy costs as well as data pertaining to the cost and efficiency of electric and gas appliances. The literature review portion of this study identifies research on each of these datasets for the case of heat in freestanding homes which currently use gas in Victoria.

This study notes that the literature review section is light on countervailing evidence. This is because there has been little attempt to undertake analysis of this form.

3.1.1 Current and Future Energy Costs

Three datasets are required to determine current and future net zero energy costs required to undertake analysis within this study.

- The AER Retail Energy Costs;
- Wholesale Energy Costs associated with AER Retail Energy Costs; and
- Net Zero Energy Costs.

Additional sensitivities around retail energy prices are also identified below.

3.1.1.1 AER Retail Energy Cost Datasets

The centrepiece of this methodology in the East Australian context is the AER's State of the Energy Market Report Chapter 6 from 2021, focused upon financial year 2020-21. While a 2022 version of this report covering FY2021-22 has been released, the AER have changed how they report retail energy bill data, removing the retail bill indexing undertaken in previous years. This lack of indexing data combined with the AER not having updated its retail gas bill breakdown since 2017 makes it impossible to undertake this analysis using the data available in the 2022 State of the Energy Market Report.

Figure 1 shows the breakdown of average retail electricity costs as found in the AER State of the Energy Market Report 2021 Chapter 6. Retail electricity costs are broken down into four components which are provided nationally and across each NEM region and the ACT.

- Wholesale Energy Costs - The cost associated with generating electricity
- Network Costs – The cost associated with transporting electricity to the retail customer

- Retail Costs & Margin – The costs and margin sought by retail energy companies
- Environmental Costs – The cost of Renewable Energy Target compliance

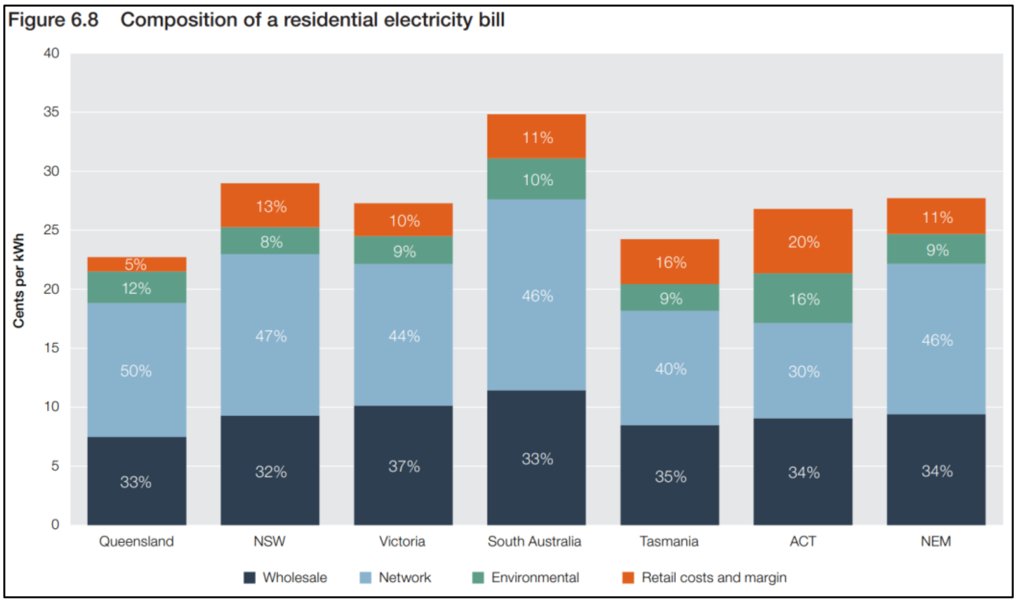

Figure 1: Composition of a residential electricity energy bill FY2020-21[1]

Figure 2 shows the breakdown of average retail gas costs as found in the AER State of the Energy Market Report 2021 Chapter 6. Retail gas costs are broken down into three components and provided nationally as well as across each NEM region and the ACT.

- Wholesale Energy Costs - The cost associated with producing gas
- Network Costs – The cost associated with transporting gas to the retail customer
- Retail Costs & Margin – The costs and margin sought by retail energy companies

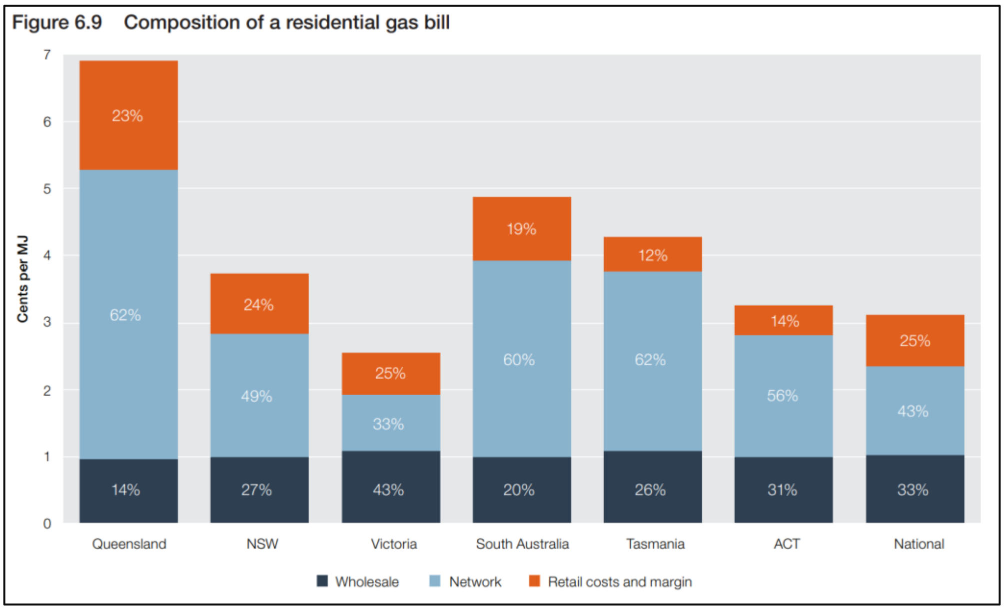

Figure 2: Composition of a residential gas energy bill CY2017[1]

[1] State of the Energy Market Report 2021 Chapter 6 Retail energy markets, Australian Energy Regulator 2021 https://www.aer.gov.au/system/files/State%20of%20the%20energy%20market%202021%20-%20Chapter%206%20-%20Retail%20energy%20markets.pdf

The AER has not analysed retail gas bill breakdown since calendar year 2017 but have provided an indexation of gas bills in each capital city of each NEM region and the ACT (Figure 3). Indexing will be applied equally to each value within the AER composition of a residential energy bill analysis to provide a conservative FY2020-21 retail gas bill cost breakdown estimate. This is considered conservative considering the relative stability or even reduction of wholesale gas market prices between CY2017 and FY2020-21 and no indication of infrastructure price increases during this period.

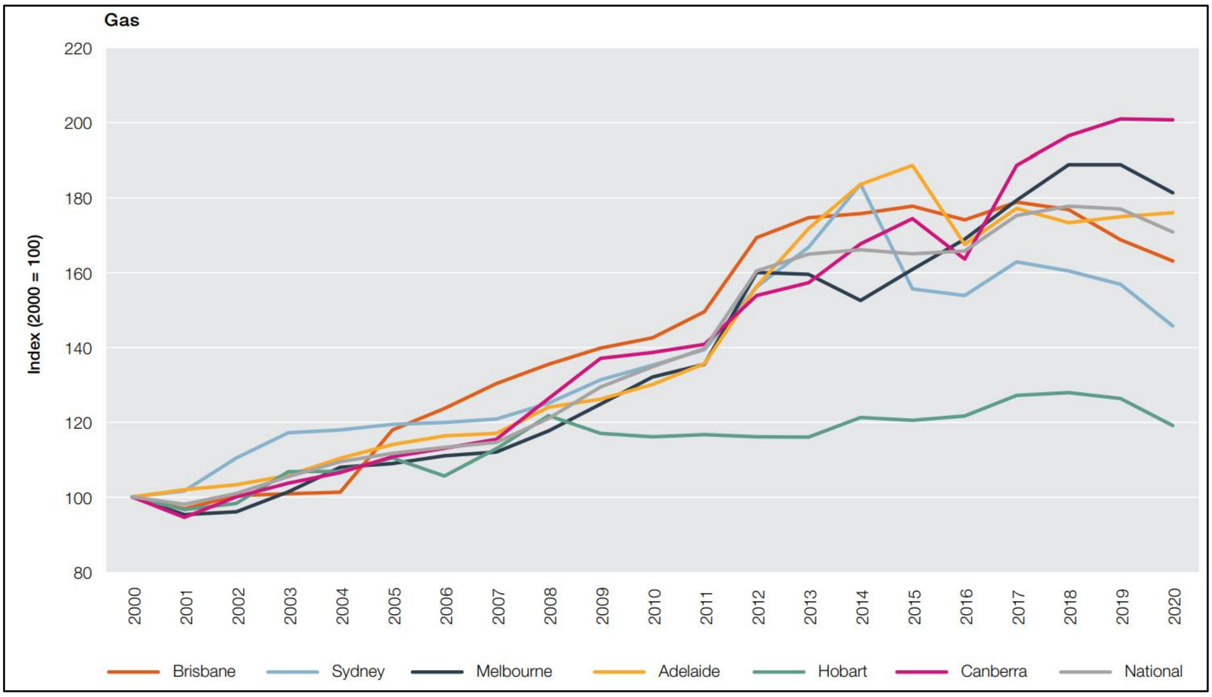

Figure 3: Gas retail price indices (inflation adjusted)[1]

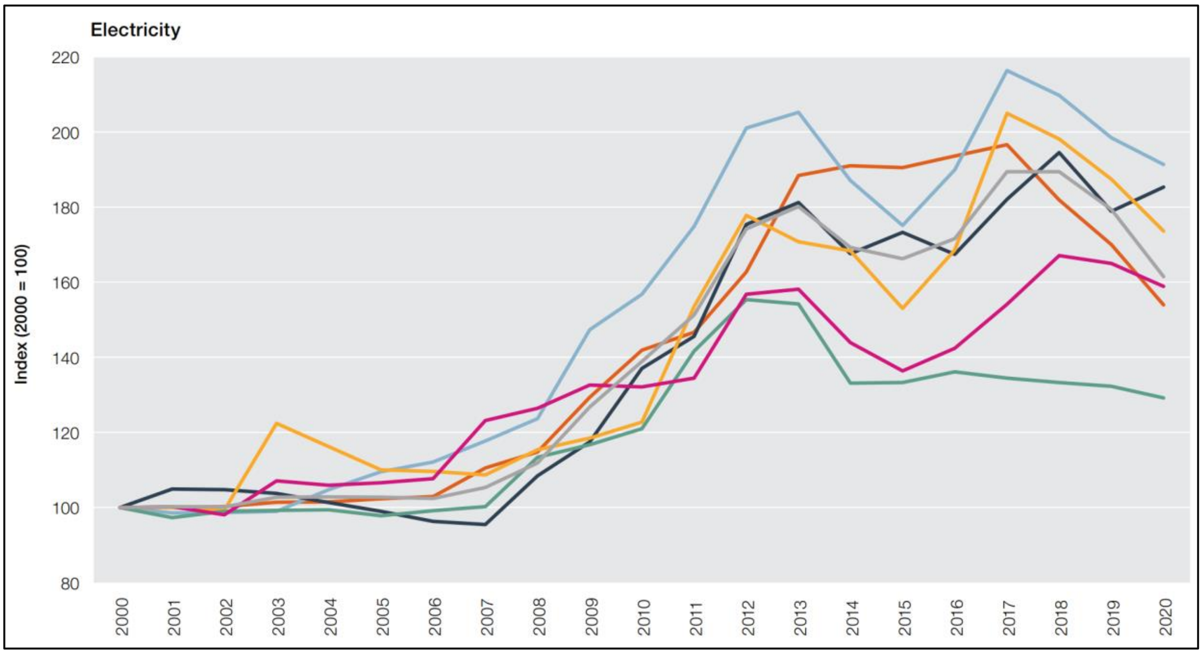

Figure 4: Electricity retail price indices (inflation adjusted)[1]

Other points to note about use of this data includes:

- Data provided on the costs of retail gas and electricity are provided in different energy units. Throughout this study, gas figures are converted from Joules units into Watt Hour units to enable like-for-like energy cost comparisons.
- Comparing AER retail electricity and retail gas energy bill costs which include retail margin and network costs ensures that the 'multiple bills' conundrum of dual fuel households is considered.

3.1.1.2Wholesale Energy Costs

AEMO provides readily available wholesale energy price datasets via their website. Table 1 contains FY2020-21 data for wholesale electricity and wholesale gas in Victoria. An online NEM data consolidation service OpenNEM was used to derive a simple calculation of average FY2020-21 Victorian NEM (VICNEM) price, while a weighted average of Declared Wholesale Gas Market (DWGM) price data for FY2020-21 is used to determine average wholesale gas price in Victoria in this study.

Table 1: Average wholesale energy prices FY2020-21

Energy Pathway	Referenced Market	Average Wholesale Energy Price FY2020-21
Electricity	VICNEM	$84.65 per MWh
Gas	DWGM	$5.94 per GJ ($21.37 per MWh)

3.1.1.3Net Zero Energy Datasets

Net zero energy datasets are broken down into the following five categories:

- Wholesale net zero electricity
- Wholesale net zero gas
- Net zero electricity infrastructure
- Net zero gas infrastructure
- Retail costs & margin and environmental costs

3.1.1.3.1 Wholesale Net Zero Electricity

Wholesale net zero electricity has been the focus of much speculation across the past decade. The Grattan Institute has speculated within its Go for Net Zero study that a wholesale price of net zero electricity may approach $99.90 per megawatt hour. This figure considers 90 per cent variable renewable electricity combined with 10 per cent firming capacity (Figure 5). Similarly, CSIRO's GenCost report produced to support AEMO electricity modelling predicts a Net Zero NEM costing as low as $75 per megawatt hour (Figure 6). These two projections provide the range of potential future prices for wholesale net zero electricity in Australia used within this study.

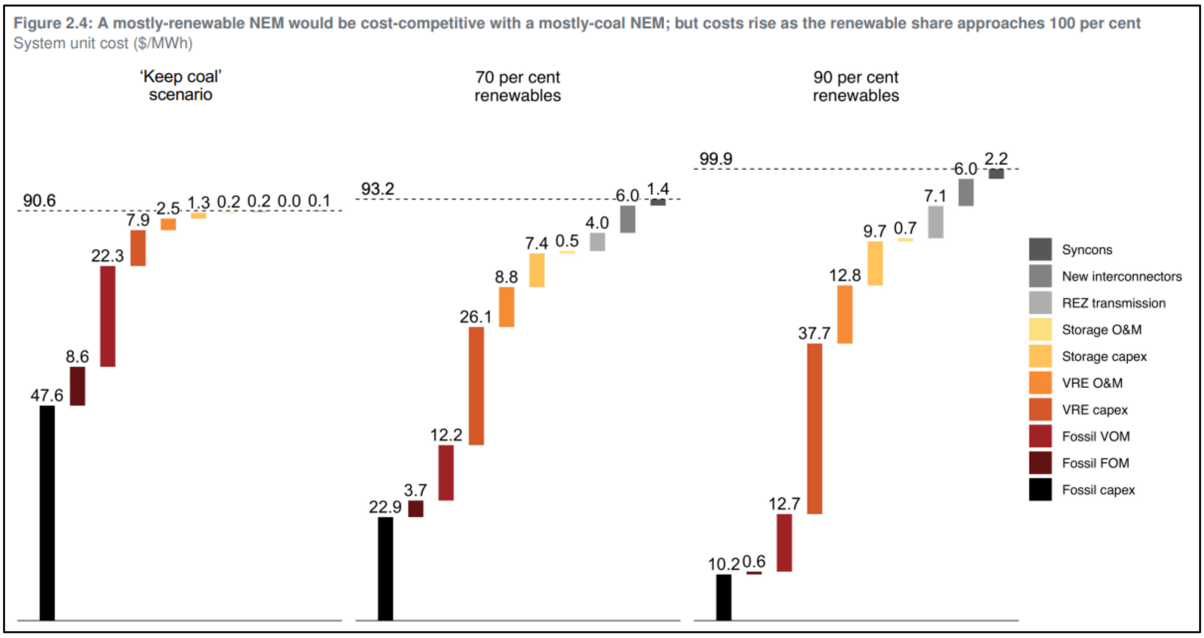

Figure 5: Average wholesale cost of electricity in a mostly renewable NEM[2]

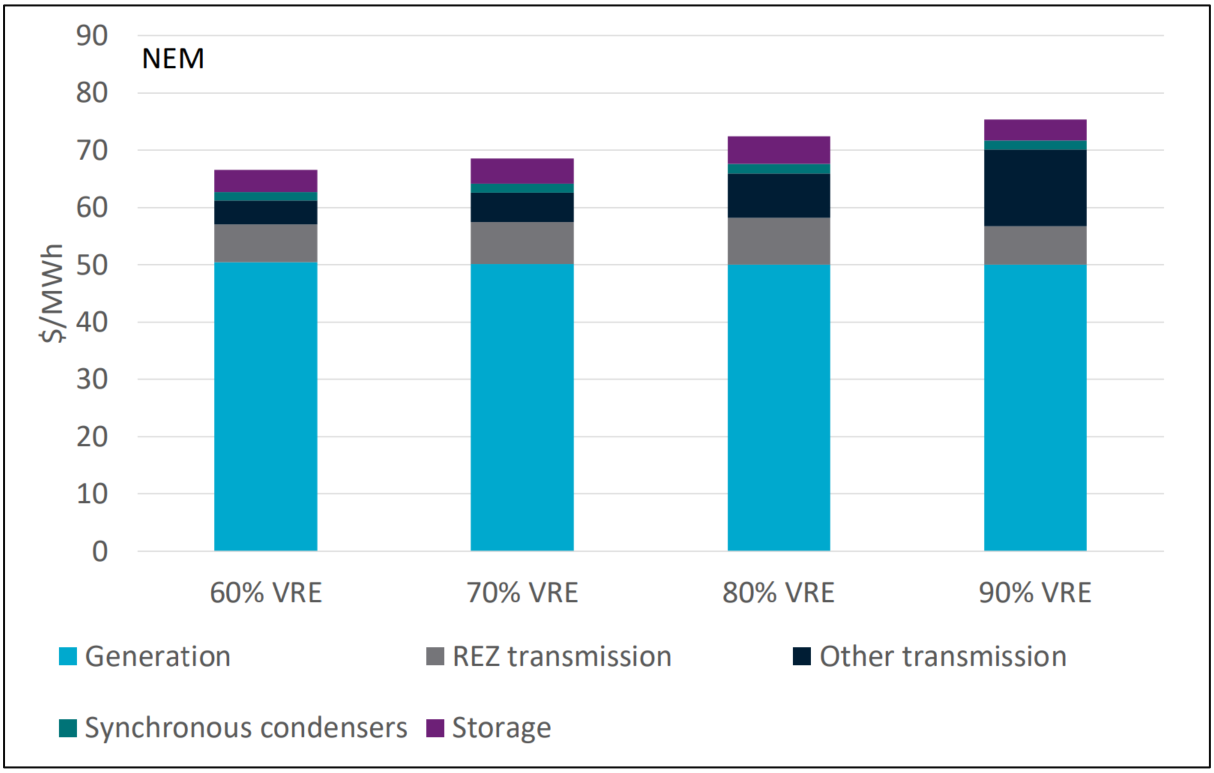

Figure 6: Levelised costs of achieving 60%, 70%, 80% and 90% annual variable renewable energy shares in NEM[3]

[2] Go for Net Zero, The Grattan Institute 2021
https://grattan.edu.au/wp-content/uploads/2021/04/Go-for-net-zero-Grattan-Report.pdf

[3] GenCost 2021-22 Final Report, CSIRO 2022
https://publications.csiro.au/publications/publication/PIcsiro:EP2022-2576

3.1.1.3.2 Wholesale Net Zero Gas

Modelling of net zero gas prices has received significantly less analysis, possible due to uncertainty about the future mixture of renewable gases. CSIRO aligns with international predictions of hydrogen approaching $4 per kilogram ($28.17 per GJ) in coming years and $2 per kilogram ($14.08 per GJ) by 2030[4], but is yet to cost biomethane. The Future Fuels CRC has priced biomethane in a range of Australian centric scenarios, deriving a wholesale cost range of $14.70 - $29.40 per gigajoule today[5]. Conveniently, predictions of future hydrogen costs and current biomethane costs align to be approximately equal, forming a practical range of future prices for wholesale net zero gas price in Australia. The range for Biomethane is used within central study scenarios to ensure conservatism as it is a marginally higher cost range.

3.1.1.3.3 Net Zero Electricity Infrastructure

Predictions of wholesale electricity cost by both CSIRO and The Grattan Institute include generation costs combined with transmission scale infrastructure, storage and system security costs. While there is sufficient information available to split these costs out and consider them separately, there is insufficient information to determine the breakdown between transmission and distribution costs in the AER retail electricity cost data.

The most conservative way to proceed in this study is for these costs to remain included as part of wholesale electricity generation costs. This does not indicate an expectation that there will be zero electricity distribution augmentation cost.

3.1.1.3.4 Net Zero Gas Infrastructure

If all renewable gases used in the future are forms of renewable methane compliant with the existing gas composition standard AS4564 – General-purpose natural gas, the cost premium of net zero gas infrastructure relative to existing infrastructure is zero. This is because there is no discernible difference between natural gas infrastructure and infrastructure for renewable gases compliant with AS4564. This is not considered within the central study scenarios to ensure conservatism, instead being considered as a sensitivity.

It is possible that the renewable gases of the future will be hydrogen centric, requiring repurposing of existing infrastructure of development of new infrastructure. Europe is leading the way in analysis of repurposing natural gas pipelines predicting repurposing costs as high as 19 per cent of the cost of new hydrogen infrastructure[6]. Comparatively, GPA Engineering recently found the price premium for new hydrogen infrastructure to be as high

[4] National Hydrogen Roadmap, CSIRO 2018
https://www.csiro.au/en/research/environmental-impacts/fuels/hydrogen/hydrogen-roadmap
[5] Future Fuels CRC, 2022
https://www.futurefuelscrc.com/
[6] The European Hydrogen Backbone initiative, 2022
https://ehb.eu/

68 per cent above the cost of natural gas infrastructure[7]. These two projections form the range of potential future renewable gas infrastructure price premiums for net zero gas which is used in this study.

3.1.1.4Retail Cost & Margin and Environmental Costs

Retail Cost & Margin and Environmental Cost factors within AER retail energy breakdowns could either be projected increasing on a prorated basis or assumed to stay the same as they are today. Assuming that these components will stay the same as they are today has been identified as the most conservative approach to take in this study.

3.1.1.5Sensitivities

This study considers three energy cost sensitivities in the sensitivities section of its analysis. As renewable electricity analysis is mature and not expected to vary greatly, sensitivities will predominantly focus on renewable gases.

<u>Low Future Hydrogen Cost</u>
While net zero electricity costs tend to consider the levelling out of technology cost curves, some speculation has started to arise in the renewable gas space with relation to hydrogen prices circa 2040. Some industry proponents have begun looking past 2030 to the 2040's, predicting hydrogen prices as low as $1 per kilogram[8]. This would result in a wholesale price of net zero energy of $25.35 per MWh. As this is a low cost sensitivity, it will be applied to the low end of the wholesale net zero gas cost range.

<u>Proportion of Rooftop Solar</u>
Noting that households have the option to introduce rooftop solar into their electricity supply mix, the study will consider a sensitivity which introduces a weighted average of 40 per cent rooftop solar at 6c per kWh ($60/MWh) into the retail energy supply mix. 40 per cent is chosen to account for reasonably daytime use without the added complexity of predicting the proportion of cost of a household battery required to address night-time heat load. This could be a further sensitivity of future analysis using the methods described within this paper.

Applying this to the low-end wholesale net zero electricity price would result in a wholesale price of net zero energy of (0.6*75) + (0.4*60) = $69/MWh wholesale price of net zero energy. Additionally, the reduction in network charges relative to the proportion of solar PV generation would need to be considered. While not a perfect approximation considering connection charges, a conservative approximation would be reducing network charged by 40 per cent. This would result in a retail cost of net zero energy network of 7.32c/kWh. As

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Pipelines vs Powerlines – A Technoeconomic Analysis in the Australian Context - full report, GPA Engineering 2022
https://www.apga.org.au/sites/default/files/uploaded-content/field_f_content_file/pipelines_vs_powerlines_-_a_technoeconomic_analysis_in_the_australian_context.pdf
8 Green Hydrogen cost tracking, Speed&Scale 2022
https://speedandscale.com/okrs/9-0-innovate/9-3-green-hydrogen/

these are low cost sensitivities, both will be applied to the low end of their relevant cost ranges.

Zero Gas Infrastructure Premium
As mentioned above, a renewable methane centric gas supply is a technically possible outcome for net zero gas in Australia. This would reduce the net zero gas infrastructure premium to zero upon current gas infrastructure costs. As this is a low infrastructure cost sensitivity, it will be applied to the low end of the net zero gas infrastructure cost range.

Table 2: Retail energy wholesale energy cost component sensitivity analysis scenarios

Sensitivity Analysis Scenario	Energy pathway	Retail Cost of Wholesale Energy FY2020-21 (c/kWh)	Wholesale Cost of Energy FY2020-21 ($/MWh)	Wholesale Cost of Net Zero Energy ($/MWh)	Scalar Wholesale Cost Difference	Retail Cost of Wholesale Net Zero Energy (c/kWh)
A	Electricity	10.12c	$84.65	$69.00	0.82	8.30c
B	Gas	3.99c	$21.37	$25.35	1.19	4.75c

Table 3: Retail energy infrastructure cost component sensitivity analysis scenarios

Sensitivity Analysis Scenario	Energy Pathway	Retail Cost of Energy Infrastructure FY2020-21 (c/kWh)	Scalar Infrastructure Cost Difference	Retail Cost of Net Zero Energy Infrastructure (c/kWh)
A	Electricity	12.01c	0.6	7.32c
C	Gas	3.07c	1	3.07c

3.1.2 Household Appliances

Three key statistics about household appliances need to be considered within this analysis:

- Appliance cost
- Appliance efficiency
- Appliance utilisation

Additional sensitivities around household appliances are also identified for testing within the analysis section of this report

3.1.2.1 Appliance Costs

This study considered replacement costs not considered in other studies including the cost to remove old gas appliances, rectifying no longer used ducting, and potential upgrading of electrical circuit boards. The study also sought to achieve the same level of heating ability as provided by the original gas appliances, as well as the possibility of providing lower levels of heating when electrifying to save on electrification costs.

The study ultimately produced relative bill savings required to achieve a break-even cost of electrification. These figures can be used to calculate the total annualised cost of new gas, hydrogen and electric appliances replacing existing gas appliances in freestanding homes in Victoria, rather than the comparative analysis provided within the report. This data is used to provide potential annualised appliance cost ranges which are used in this study.

Note that this report is the key locational constraint on this study as the Frontier Economics study only consider appliance costs in Victoria.

Table 4: Range of annualised total appliance costs to provide equivalent heating in a freestanding homes using gas heating today

Energy Pathway	Appliance	Annualised Total Appliance Cost[9]
Electricity	Heat Pump High	$5,913
	Heat Pump Low	$1,638
Gas	Gas Appliance High	$2,026
	Gas Appliance Low	$857
	Hydrogen Appliance High	$2,192
	Hydrogen Appliance Low	$1,011

For the avoidance of doubt, this study acknowledges that it has only considered the customer appliance case of replacing existing gas appliances in freestanding Victorian homes. There are many other customer use cases that can be considered using the methodology proposed within this study, however one case has been used for simplicity of methodology demonstration. This study does not seek to conclude that other customer appliance use cases have equivalent results. Rather, the study invites further investigation of other use cases using the proposed methodology.

3.1.2.2Appliances Efficiencies

Data on the efficiency of both electric heat pump and gas appliances has been relatively well documented for some time. Appliance efficiency ranges used within this study can be found in Table 5 below. The Australian Building Codes Board Whole-of-Home Efficiency Factors Standard used within the National Construction Code considers heat pump appliances with average efficiencies between 300 per cent to 600 per cent alongside gas appliances with average efficiencies between 70 per cent and 90 per cent[10].

This study considers that heat pump appliances are typically used in periods or service which reduce their actual efficiency at the point in time which the appliance is used. This is due to cold ambient temperature in the case of space heating or maintaining an above ambient water bath temperature in the case of hot water heating. Studies by the Australian Government displays a reduction in efficiency of around 50 per cent to 150 per cent due to

[9] Cost of switching from gas to electric appliances in the home, Frontier Economics 2022 https://gamaa.asn.au/wp-content/uploads/2022/07/Frontier-Economics-Report-GAMAA.pdf
[10] Whole-of-Home Efficiency Factors Standard, Australian Building Codes Board 2022 https://ncc.abcb.gov.au/sites/default/files/resources/2022/whole-of-home-efficiency-factors-2022.pdf

each factor[11], and these findings are supported by data recently published by Mitsubishi Electric[12]. This study will consider the minimum of this efficiency reduction range as a conservative approach to considering heat pump efficiency at the time of appliance use.

Table 5: Range of appliance efficiencies

Appliance	Efficiency Case	Average Efficiency	Inefficient Service Penalty	Time of use Efficiency
Heat Pump	High	600%	-50%	550%
	Low	300%	-50%	250%
Gas or Hydrogen	High	90%	0%	90%
	Low	70%	0%	70%

While these figures will be used to consider whole of home efficiency, electric stoves do not exceed an energy efficiency of 100 per cent. Due to the relatively small proportion of household heating energy used in cooking, this study takes the conservative approach of not considering this reduction in average efficiency for electrified households.

3.1.2.3Appliance Utilisation

Gas appliance utilisation will be based upon the AER Residential Energy Consumption Benchmarks. The 2020 Benchmark for gas use in Victoria as determined by the AER is 49,799 megajoules per annum[13].

3.1.2.4Victorian Home Heat Energy Demand

This study combines appliance utilisation and efficiency data to determine the quantum of heat required in the average Victorian home. From this, the quantum of electricity required to provide the same level of heating is also determined.

Analysis starts with average gas appliance energy utilisation to which the range of possible gas appliance efficiencies is applied to determine the quantity of heat energy demand in kilowatt hours thermal (kWht). The range of electric appliance efficiencies is then be applied to determine the range of potential electricity input quantities required to provide the same quantity of heat in the home via electric appliances.

[11] Product Profile: Heat Pump Water Heaters, Commonwealth of Australia 2021
https://www.energyrating.gov.au/sites/default/files/documents/Heat-Pump-Water-Heater-Product-Profile-June-2012-1_0.pdf

[12] Heating Capacity Chart Ceiling Cassette Model PLA-M71EA-A:SUZ-M71VAD-A, Mitsubishi Electric 2021
https://www.mitsubishi-electric.co.nz/materials/Aircon/Performance_Charts/@PLA-M,%20PKA-M,%20PA-M,%20PEAD-M,%20PEA-M_2021-JUNE.pdf

[13] Residential energy consumption benchmarks, Frontier Economics 2020
https://www.aer.gov.au/system/files/Residential%20energy%20consumption%20benchmarks%20-%209%20December%202020_0.pdf

Table 6: Home Heat Demand Range

<table>
<tr><th>Gas Energy Demand</th><th colspan="2">Gas Appliance Efficiency Range</th><th>Home Heat Demand Range</th><th colspan="2">Electric Appliance Efficiency Range</th><th>Electric Energy Demand</th></tr>
<tr><td rowspan="4">13,833kWhpa</td><td rowspan="2">High Efficiency</td><td rowspan="2">90%</td><td rowspan="2">12,450kWhtpa</td><td>Low Efficiency</td><td>250%</td><td>4,980kWhpa</td></tr>
<tr><td>High Efficiency</td><td>550%</td><td>2,264kWhpa</td></tr>
<tr><td rowspan="2">Low Efficiency</td><td rowspan="2">70%</td><td rowspan="2">9,683kWhtpa</td><td>Low Efficiency</td><td>250%</td><td>3,873kWhpa</td></tr>
<tr><td>High Efficiency</td><td>550%</td><td>1,761kWhpa</td></tr>
</table>

Note: Maximum and Minimum electricity demand for electrical energy pathway identified in **bold**

3.1.2.5Sensitivities

This study considers two household appliance sensitivities. As gas appliances are reasonably mature technologies, sensitivities will focus on electric appliances.

<u>Resistive Heating Element Efficiency</u>

Electric heat pumps can achieve substantial efficiencies providing heat in warm weather conditions. However, heating is most commonly required in cold conditions, and a storage hot water systems rarely heats its water bath from ambient temperature. Appliance manufacturers in Europe have addressed this issue by having backup resistive heating elements built into heat pump appliances for use in cold conditions, with the United Kingdom similarly considering resistive heating loads for peak electricity demand[14,15].

Even if Australian regulation restricts the use of resistive heating backup elements in Australian heat pump appliances, it is likely that all electric households would purchase portable resistive heaters if their heat pump appliance failed to provide the heat they require. Considering this, an electric appliance efficiency of 100 per cent is considered as a sensitivity. As this is a high demand sensitivity, it will be applied to the high end of the Home Heat Demand range.

<u>High Heat Pump Efficiency</u>

Heat pump advocates often reference efficiencies well above the maximum efficiency considered by the Australian Building Code Board. Despite this, in order to consider the possibility of higher efficiency heat pumps in the future, an electric appliances efficiency of

[14] European Heating Industry Association 2022,
https://ehi.eu/

[15] Hybrid Heat Pumps Final Report, United Kingdom Department for Business, Energy & Industrial Strategy, 2017
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf

900 per cent will be considered as a sensitivity[16]. As this is a low demand sensitivity, it will be applied to the low end of the Home Heat Demand range.

Table 7: Home Heat Demand Range Sensitivities & Impacts on Electricity Demand

Sensitivity Analysis Scenario	Gas Energy Demand	Gas Appliance Efficiency Range		Home Heat Demand Range	Electric Appliance Efficiency Range		Electric Energy Demand
D	13,833kWhpa	Low Efficiency	70%	9,683 kWhtpa	Very High Efficiency Heat Pump	900%	1,076 kWhpa
E		High Efficiency	90%	12,450 kWhtpa	Resistive Heat Element	100%	12,450 kWhpa

[16] APGA is not aware of any commercially available heat pump appliances at this efficiency.

3.2 Customer cost of heat in the home FY2020-21

Customer cost of heating in the home in FY2020-21 is modelled by combining modelled bill costs for each energy pathway today with modelled appliance costs for each energy pathway.

3.2.1 Bill Costs per Unit Heat Energy

Bill costs are determined by multiplying the AER determined average cost of retail energy with the quantity of energy input into gas or electric appliances and dividing these by the quantity of heat required in the average Victorian home. As seen in Section 3.1.2.4 above, the range of gas appliance efficiencies result in a range of quantities of heat required in the average Victorian home. This further resolves in the following range of average bill costs for heat in the average Victorian home as seen in Table 8.

Table 8: Range of energy bill cost per unit heat in the average Victorian home

Energy Required			Retail Cost	Heat Demand		Bill Cost per Unit Heat
Gas	Average	13,833 kWhpa	9.36 c/kWh	High	12,450kWhtpa	10.4c/kWht
				Low	9,683kWhtpa	13.4c/kWht
Electricity	High	4,980 kWhpa	27.28 c/kWh	High	12,450kWhtpa	10.9c/kWht
	Low	1,761 kWhpa		Low	9,683kWhtpa	5.0c/kWht

3.2.2 Appliance Costs per Unit Heat Energy

The range of appliance costs per unit heat energy output is determined by dividing the maximum and minimum appliance costs for gas and electric appliances by the maximum and minimum level of heat demand of the average Victorian home. This derives a range of appliance costs per unit heat output for each appliance type as seen in Table 9.

Table 9: Appliance cost per unit heat in the average Victorian home

Residential Heat Demand		Annualised Appliance Cost			Appliance Cost per Unit Heat Demand
Low	9,683kWhtpa	Electricity	High	$5,913	**61.1c/kWht**
			Low	$1,638	16.9c/kWht
		Gas	High	$2,026	**20.9c/kWht**
			Low	$857	8.9c/kWht
High	12,450kWhtpa	Electricity	High	$5,913	47.5c/kWht
			Low	$1,638	**13.2c/kWht**
		Gas	High	$2,026	16.3c/kWht
			Low	$857	**6.9c/kWht**

Note: Maximum and Minimum for each energy pathway identified in **bold**

3.2.3 Combined Customer Cost per Unit Heat Energy

Combining ranges for modelled bill cost per unit heat energy with ranges for modelled appliance cost per unit heat energy produces the modelled customer cost of heating in the home in FY2020-21 as seen in Table 10 and Figure 7.

Table 10: Victorian Customer Cost of Heat in the Home FY2020-21

Energy Pathway	Bill Cost per Unit Heat		Appliance Cost per Unit Heat		Cost per Unit Heat
Electricity	High	10.9c/kWht	High	61.1c/kWht	72.0c/kWht
	Low	5.0c/kWht	Low	13.2c/kWht	18.2/kWht
Gas	High	13.4c/kWht	High	20.9c/kWht	34.3c/kWht
	Low	10.4c/kWht	Low	6.9c/kWht	17.3c/kWht

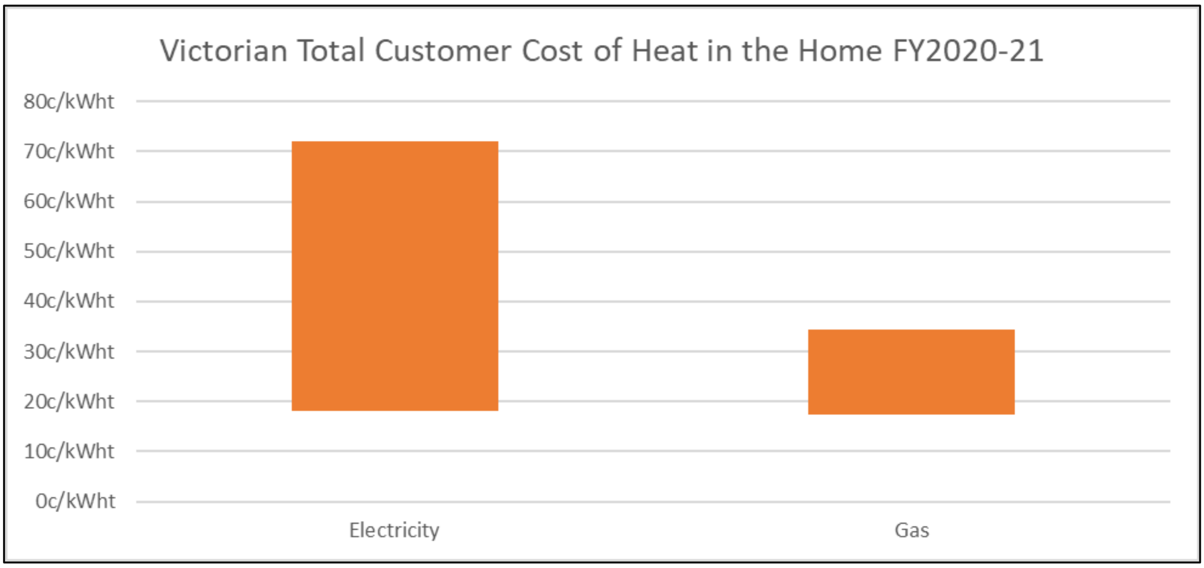

Figure 7: Victorian Total Customer Cost of Heat in the Home FY2020-21

Note that the minimum customer cost of heat in the home is lower for gas than electricity, and that the customer cost range for gas is narrower and lower than the range for electricity. This demonstrates the current cost competitiveness and stability of gas home heating costs in Victoria as of FY2020-21. This cost competitiveness and stability predicts substantial utilisation of gas for heat in freestanding Victorian homes, which in turn aligns with the current dominances of gas use for heat in the home in the State.

3.2.4 Breakdown of constituent components impacting customer cost

Figure 8displays the scale of the impact of each of the customer cost components analysed within this study, demonstrating that some factors impact customer cost of heat in the home greater than others. The impact of variations in component costs can be seen in in Figure 9, demonstrating that variations in appliance cost creates the greatest variation in customer cost of heat in the home, followed by appliance efficiency.

As referenced datasets for FY2020-21 include specific average cost of wholesale energy and energy networks, there is no variation seen in either of these components. Referenced datasets include ranges for appliance cost and appliance efficiency, hence these are seen to create variability in customer cost. Note that the of potential appliance costs have a greater impact on variability in customer cost of heat in the home compared to the range of appliance efficiencies.

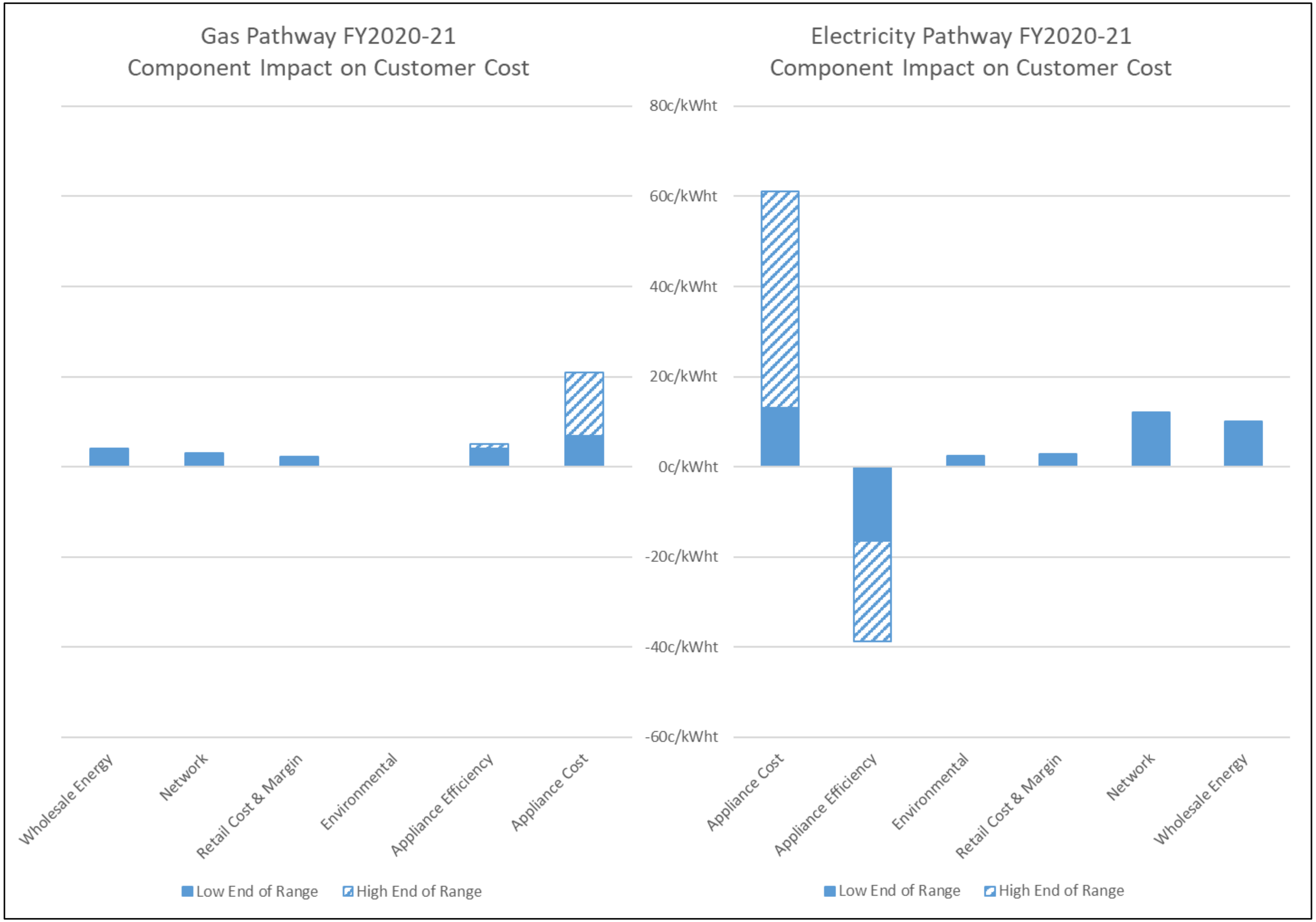

Figure 8: Customer cost range for net zero heat in the home component cost breakdown

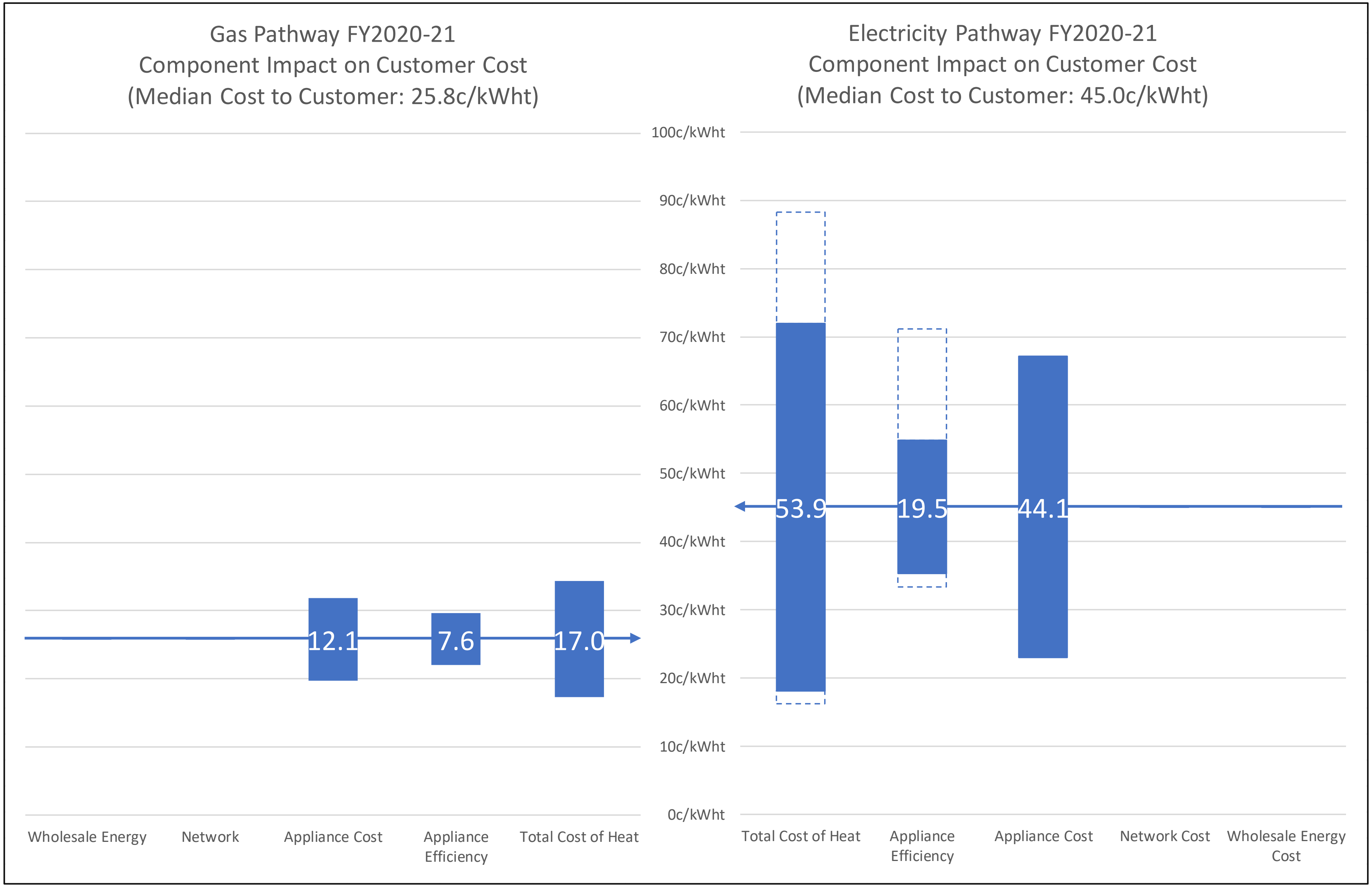

Figure 9: Variations in customer cost range for heat in the home in FY2020-21 component cost breakdown

3.2.4.1 Impact of increasing energy prices

The reality of increasing gas prices in both recent years and near-term projections may call the above conclusions into question. This outcome is in part explained by the similarities in retail electricity and gas bill indexing across recent years and by the dominance of appliance costs seen in Figure 8. The relative difference in gas and electricity price has not changed much in recent years as seen in Figure 3 and Figure 4, and the impact of retail energy price on total customer cost is outweighed by the impact of appliance cost.

A similar outcome is demonstrated when considering the retail price increase projections from the October 2022 federal budget. Within this budget the federal government projected a 44 per cent increase in retail gas prices and a 56 per cent increase in retail electricity prices. The result of applying these increases to FY2020-21 retail energy data can be seen in Section 3.2.5 below.

3.2.4.2 Application of Sensitivity Analysis Scenarios

Also seen in Figure 9 is the result of applying Sensitivity Analysis Scenarios D & E. Core analysis has focused on the assumption that the overwhelming majority of heat demand in an electrified home will be achieved through the deployment of heat pumps appliances. While core analysis uses conservative data for heat pump efficiencies, it is worth considering sensitivities relative to different electric appliance efficiencies. Sensitivity Analysis Scenario D reflects the use of very high efficiency heat pumps with an efficiency of 900 per cent, and Sensitivity Analysis Scenario E reflects the use of resistive heat elements or induction cooktops with a maximum efficiency of 100 per cent.

As seen in Figure 10, the improvement to customer cost of heat in the home reaches a point of diminishing returns through the application of higher efficiency heat pumps. This is predominantly due to the substantial impact of appliance cost and the small reduction in electricity consumption between 550 per cent and 900 per cent efficient heat pump appliances. It is also unlikely that minimum appliance cost would occur at the same time as maximum heat pump efficiency. On the other hand, the application of traditional heating element appliances or induction cooktops has a substantial impact on the upper cost of heating in the home considering the substantial increase in electricity use by returning to 100 per cent efficiency from 250 per cent.

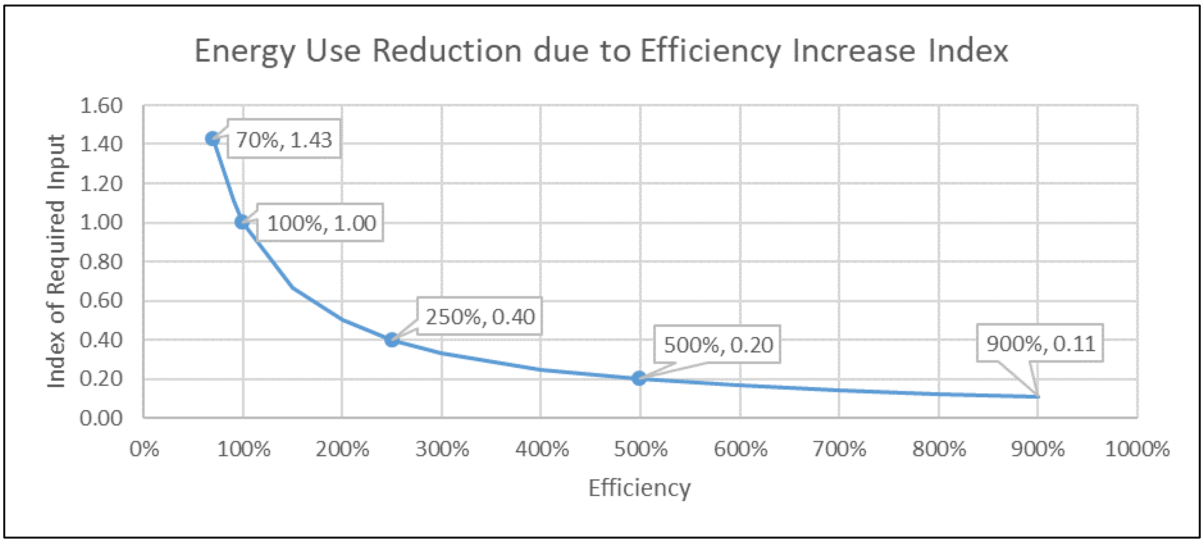

Figure 10: Energy Use Reduction due to Efficiency Increase Index

Sensitivity E is an important sensitivity considering that many heat pump applications globally in climate regions similar to Melbourne use resistive heating element backup to ensure heat is maintained when temperatures reach their coldest[17]. Even if resistive backup elements are regulated out in Australian heat pump appliances, it is reasonable to expect that an all-electric household would seek off the shelf resistive heating appliances in the event that heat pump appliances underperform in cold conditions.

The application of Sensitivity Analysis Scenarios D & E is further summarized in Figure 11 below to align with Figure 9 above.

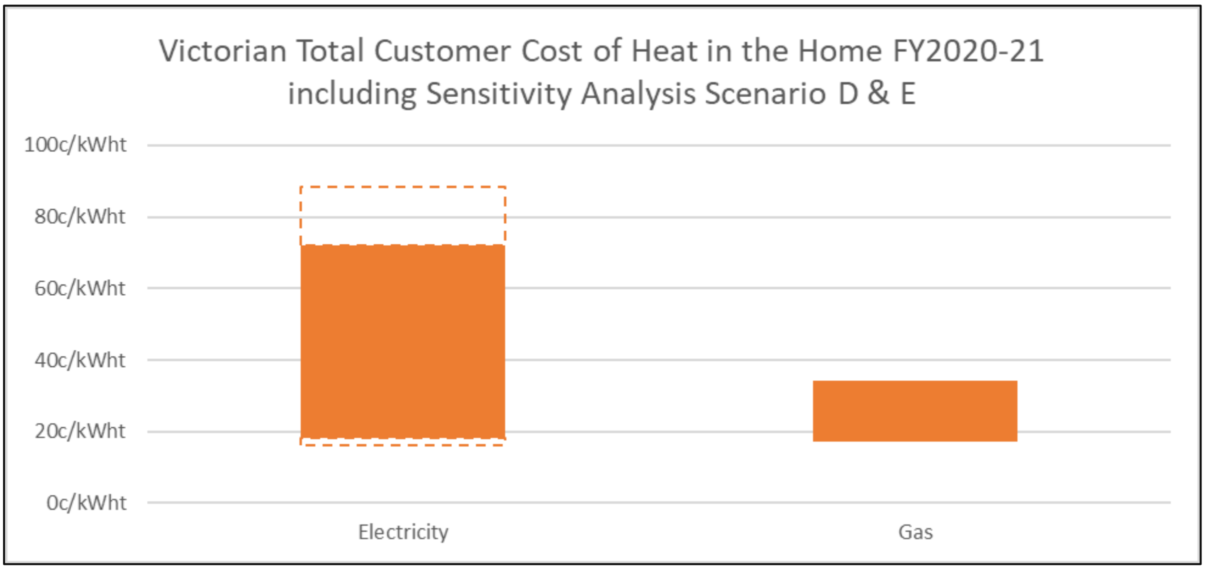

Figure 11: Victorian Total Customer Cost of Heat in the Home FY2020-21 including Sensitivity Analysis Scenario D & E

[17] Association of the European Heating Industry, 2022
https://ehi.eu/

3.2.5 Customer cost of heat in the home circa 2024

The updated FY2022-23 federal budget released 25 October 2022 indicated substantial retail energy price rises through to 2024[18]. Retail electricity prices have been predicted to increase 56 per cent and retail gas prices are anticipated to increase by 44 per cent by 2024. Undertaking the same analysis with retail energy prices scaled in line with budget estimates produces the following outcome for total customer cost of heat in freestanding Victorian homes which use gas today.

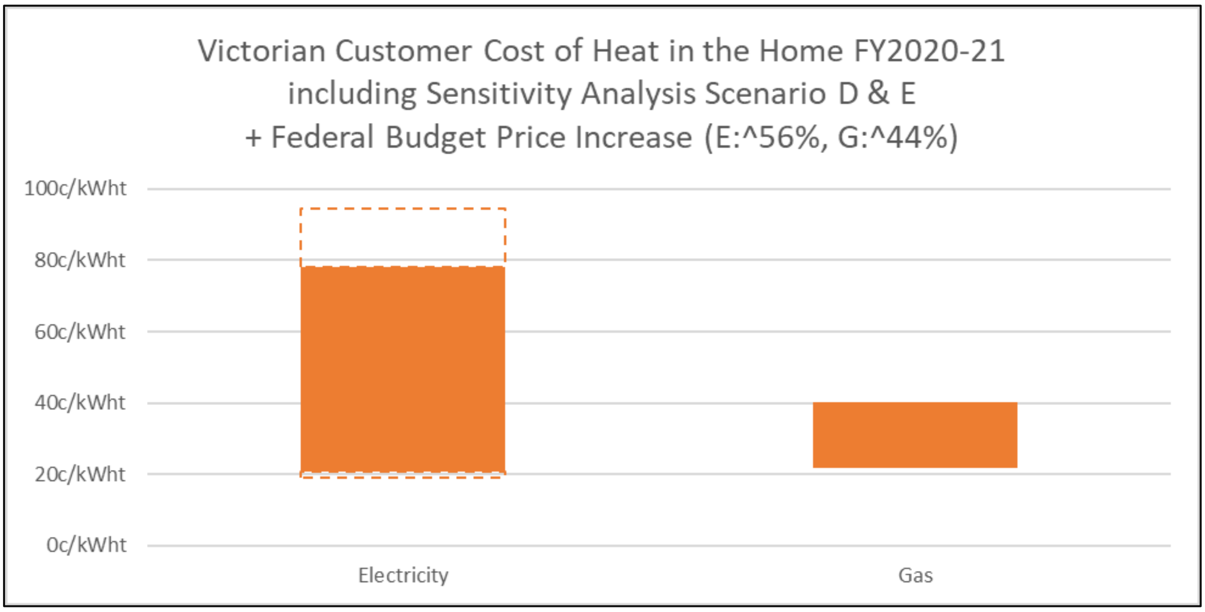

Figure 12: Victorian Customer Cost of Heat in the Home FY2020-21 including Sensitivity Analysis Scenario D & E + Federal Budget Price Increase (E:^56%, G:^44%)

As seen in Figure 12, the relative difference between the total customer cost of heat in the home as delivered by electricity and gas energy pathways does not change. This is despite all household energy customers paying more for heat than seen in Figure 11. Despite retail gas price increases, gas customers will still be financially better of continuing to use gas following the federal budget retail price increase predictions than if they were to electrify their heat energy demand.

[18] Official Federal Budget Website 2022
https://budget.gov.au/index.htm

3.3 Customer cost of net zero heat in the home

The supply chain analysis methodology can be used to model the customer cost of net zero heating in the home by modelling retail net zero energy costs for use within the methodology. This analysis is based on the opportunity for both electricity and gas supply chains to be decarbonised using either renewable electricity or renewable gases.

The following analysis first models the retail cost of net zero electricity and net zero gas by augmenting AER energy bill breakdown data with net zero energy wholesale production and infrastructure cost data. Modelled retail costs are then fed into similar analysis as performed above to model customer cost of heating in the home in FY2020-21 in order to model the customer cost of net zero heating in the home.

3.3.1 Retail Cost of Net Zero Energy

Retail cost of net zero energy analysis starts with the AER data on gas and electricity energy bill breakdown for Victoria. From this starting point, data pertaining to current and future energy production and infrastructure costs are applied to AER data to model changes in bill components in a net zero future. This can be seen in Table 11 and Table 12 below, noting that net zero electricity infrastructure is assumed to experience no change as detailed in Section 3.1.1.3.3 above. Combining this information with current Retail Cost & Margin data and Environmental Cost data resolves the modelled retail cost of net zero electricity and net zero gas as seen in Table 13 and Figure 13.

Table 11: Modelled whole energy cost component of retail net zero energy price in Victoria

Energy pathway	Retail Cost of Wholesale Energy FY2020-21 (c/kWh)	Wholesale Cost of Energy FY2020-21 ($/MWh)	Net Zero Energy Cost Case	Wholesale Cost of Net Zero Energy ($/MWh)	Scalar Wholesale Cost Difference	Retail Cost of Wholesale Net Zero Energy (c/kWh)
Electricity	10.12c	$84.65	High	$99.88	1.18	11.94c
			Low	$75.00	0.89	8.97c
Gas	3.99c	$21.37	High	$105.84	4.95	19.77c
			Low	$52.92	2.48	9.88c

Table 12: Modelled infrastructure cost component of retail net zero energy price in Victoria

Energy Pathway	Retail Cost of Energy Infrastructure FY2020-21 (c/kWh)	Net Zero Energy Infrastructure Cost Case	Scalar Infrastructure Cost Difference	Retail Cost of Net Zero Energy Infrastructure (c/kWh)
Gas	3.07c	High	1.68	5.15c
		Low	1.19	3.65

Table 13: Modelled retail net zero energy prices in Victoria

Energy Pathway	Net Zero Energy Cost Pathway	Retail Cost of Wholesale Net Zero Energy (c/kWh)	Retail Cost of Net Zero Energy Infrastructure (c/kWh)	Retail Cost of Retail Margin & Enviro. Costs (c/kWh)	Retail Cost of Net Zero Energy (c/kWh)
Electricity	High	11.94c	12.01c	5.15c	29.10c
	Low	8.97c			26.13c
Gas	High	19.77c	5.15c	2.30c	27.21c
	Low	9.88c	3.65c		15.83c

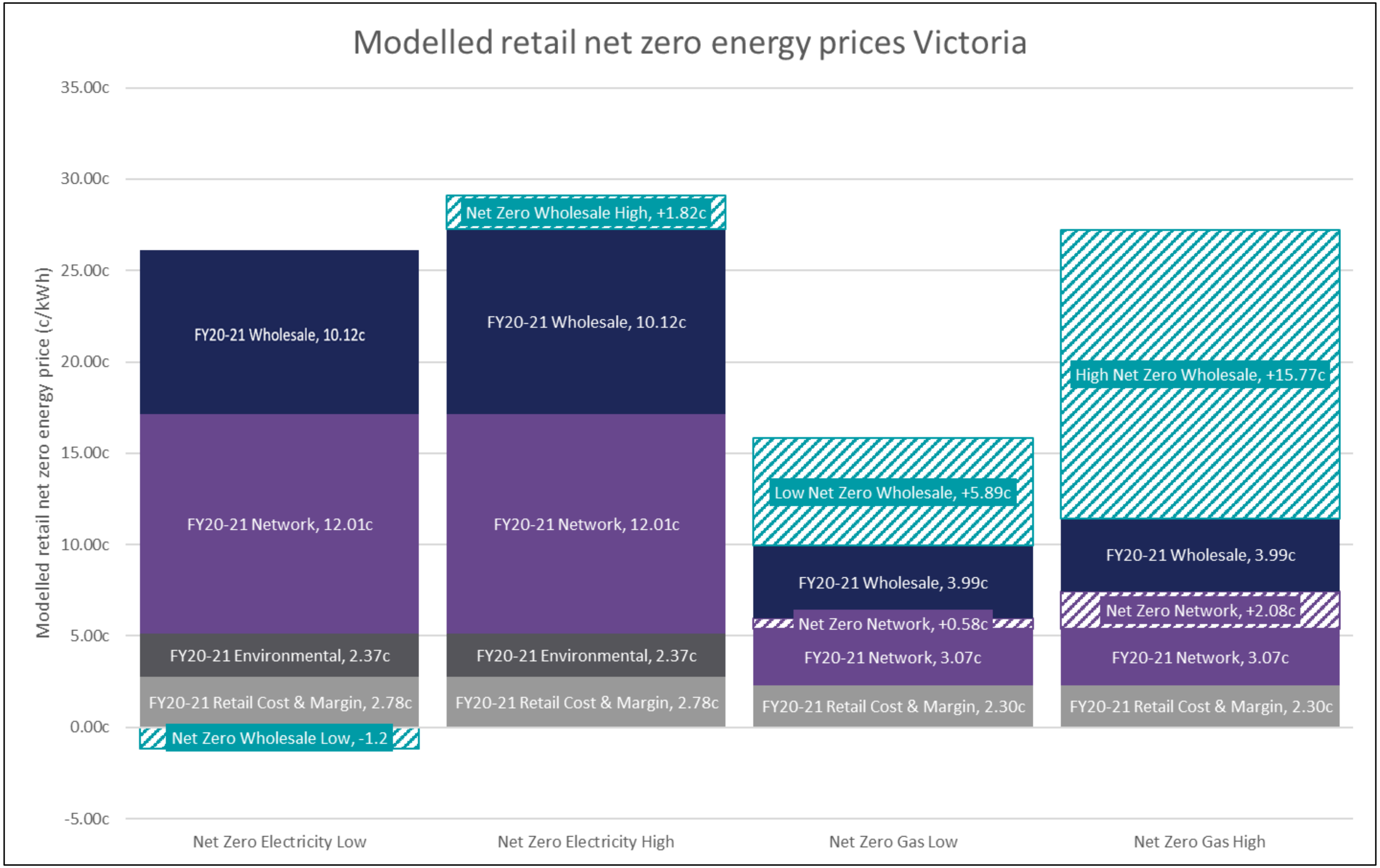

Figure 13: Modelled retail net zero energy prices Victoria

3.3.2 Customer Cost of Net Zero Heat in the Home

Customer cost of net zero heating in the home is modelled by combining modelled bill costs for each net zero energy pathway with modelled appliance costs for each net zero energy pathway.

3.3.3 Bill Costs per Unit Heat Energy

Bill costs are modelled by multiplying the modelled cost of retail net zero energy with the quantity of energy input into net zero gas or electric appliances and dividing these by the quantity of heat required in the average Victorian home. As seen in Section 3.1.2.4 above however, the range of gas appliance efficiencies result in a range of quantities of heat required in the average Victorian home. This further resolves in the following range of average bill costs for net zero heat in the average Victorian home as seen in Table 14.

Table 14: Range of net zero energy bill cost per unit heat in the average Victorian home

Energy Required			**Retail Cost**		**Heat Demand**		**Bill Cost per Unit Heat**
Net Zero Gas	Avg.	13,833 kWhpa	Low	15.8c/kWh	High	12,450kWhtpa	**17.6c/kWht**
					Low	9,683kWhtpa	22.6c/kWht
			High	27.2c/kWh	High	12,450kWhtpa	**38.9c/kWht**
					Low	9,683kWhtpa	30.2c/kWht
Net Zero Electricity	High	4,980 kWhpa	Low	26.1c/kWh	High	12,450kWhtpa	10.5c/kWht
			High	29.1c/kWh	High	12,450kWhtpa	**11.6c/kWht**
	Low	1,761 kWhpa	Low	26.1c/kWh	Low	9,683kWhtpa	**4.8c/kWht**
			High	29.1c/kWh	Low	9,683kWhtpa	5.3c/kWht

Note: Maximum and Minimum for each energy pathway identified in **bold**

3.3.4 Appliance Costs per Unit Heat Energy

The range of appliance costs per unit net zero heat energy output is determined by dividing the maximum and minimum appliance costs for net zero gas and electric appliances by the maximum and minimum level of heat demand of the average Victorian home. This derives a range of appliance costs per unit net zero heat output for each appliance type as seen in Table 15.

Table 15: Appliance cost per unit heat in the average Victorian home

Residential Heat Demand		Annualised Appliance Cost			Appliance Cost per Unit Heat Demand
Low	9,683kWhtpa	Net Zero Electricity	High	$5,913	**61.1c/kWht**
			Low	$1,638	16.9c/kWht
		Net Zero Gas	High	$2,192	**22.6c/kWht**
			Low	$1,011	10.4c/kWht
High	12,450 kWhtpa	Net Zero Electricity	High	$5,913	47.5c/kWht
			Low	$1,638	**13.2c/kWht**
		Net Zero Gas	High	$2,192	17.6c/kWht
			Low	$1,011	**8.1c/kWht**

Note: Maximum and Minimum for each energy pathway identified in **bold**

3.3.5 Combined Customer Cost per Unit Heat Energy

Combining ranges for modelled bill cost per unit heat energy with ranges for modelled appliance cost per unit heat energy produces the modelled customer cost of net zero heating in the home as seen in Table 16 and Figure 14.

Table 16: Victorian Customer Cost of Net Zero Heat in the Home

Energy Pathway	Bill Cost per Unit Heat		Appliance Cost per Unit Heat		Cost per Unit Heat
Electricity	High	11.6c/kWht	High	61.1c/kWht	72.7c/kWht
	Low	4.8c/kWht	Low	13.2c/kWht	17.9c/kWht
Gas	High	38.9c/kWht	High	22.6c/kWht	61.5c/kWht
	Low	17.6c/kWht	Low	8.1c/kWht	25.7c/kWht

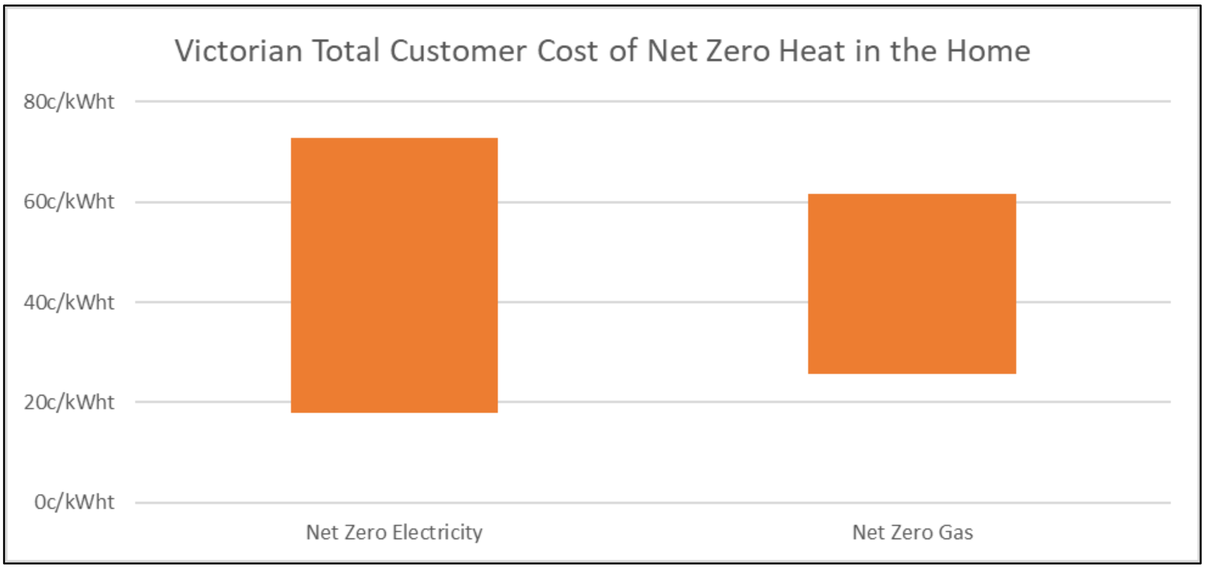

Figure 14: Victorian Customer Cost of Net Zero Heat in the Home

Note that the range of cost for customer cost of heating in the home for net zero gas is narrower and aligned with the range for net zero electricity, with the median point marginally lower for gas compared to electricity. This demonstrates the future cost competitiveness and price stability of net zero gas for providing heating in the home in Victoria. This cost competitiveness and stability predicts substantial utilisation of net zero gas for heat in the home in a net zero Victoria.

3.3.6 Breakdown of constituent components impacting customer cost

Figure 15 displays the scale of the impact of each of the customer cost components analysed within this study, demonstrating that some factors impact customer cost of heat in the home greater than others. The impact of variations in component costs can be seen in in Figure 16, demonstrating that variations in appliance cost still creates the greatest variation in customer cost of net zero heat in the home, followed by appliance efficiency.

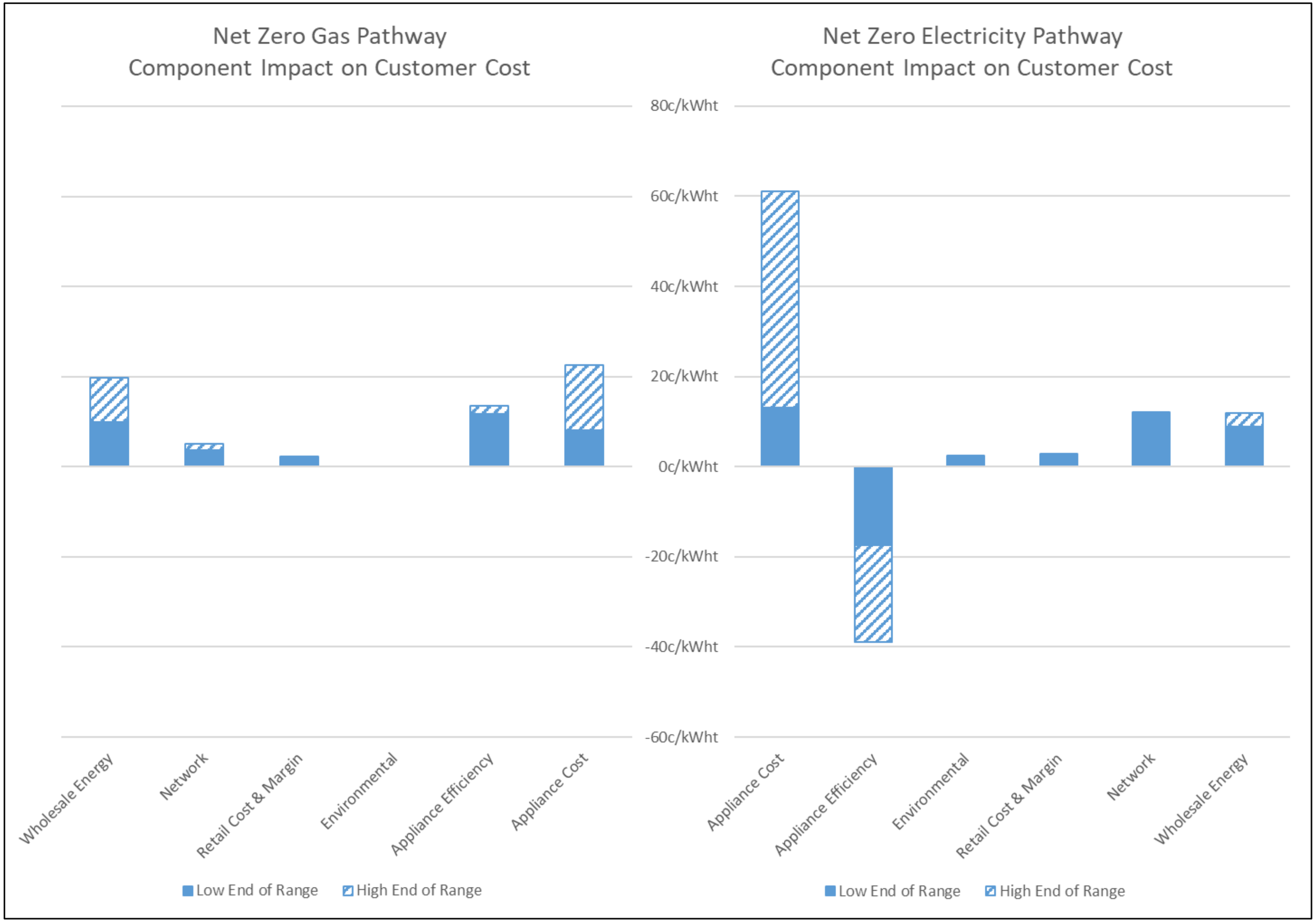

Figure 15: Customer cost range for net zero heat in the home component cost breakdown

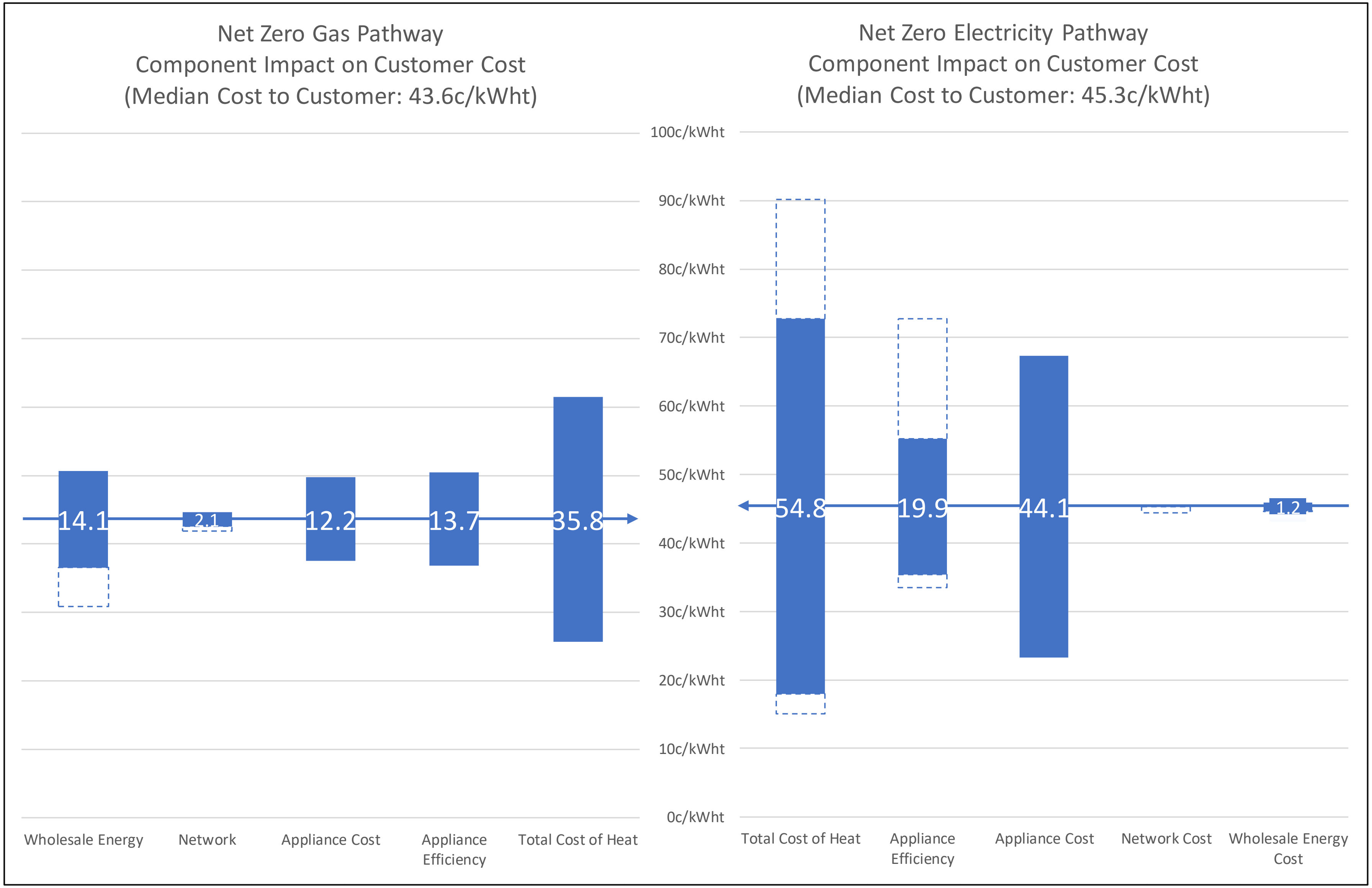

Figure 16: Variations in customer cost range for net zero heat in the home component cost breakdown

3.3.6.1 Application of Sensitivity Analysis Scenarios

Also seen in Figure 16 are Sensitivity Analysis Scenarios A, B, and C alongside scenarios D and E as described in Section 3.2.4.1 which have a similar impact in analysis of net zero heat in the home. Scenarios A and B consider lower retail energy costs through the use of either rooftop solar or lower cost renewable gases, while scenario C considered the impact of no renewable gas infrastructure premium from a renewable methane centric future.

Considering 40 per cent rooftop solar use in electric heating appliances reduces both the wholesale cost impact and infrastructure cost impacts for the renewable electricity pathway. However, as is seen in Figure 16, the relative impacts of these changes on total customer cost are quite small in proportion to the appliance cost and efficiency impacts. Adding all cost reductions from Sensitivity Analysis Scenarios A and D only reduces minimum customer cost of heat in the home by a further 2,8c per kWht below the 17.9c minimum. As noted previously, it is unlikely that lowest cost heat pump appliances will be highest efficiency heat pump appliances and vice versa.

Sensitivity Analysis Scenarios B and C consider two separate circumstances which may further reduce the cost of net zero heat in the home. The reduction in wholesale hydrogen cost to $1 per kilogram has been flagged as a post 2030 possibility by some in the industry, potentially halving wholesale renewable gas price. Alternately, if a methane centric renewable gas supply chain eventuates, the cost premium for hydrogen infrastructure. These both represent cost to customer reductions of 5.7c and 0.6c respectively, however are unlikely to occur simultaneously.

The application of Sensitivity Analysis Scenarios A, B, C, D & E to customer cost of net zero heat in the home is further summarized in Figure 17 below to align with Figure 16 above.

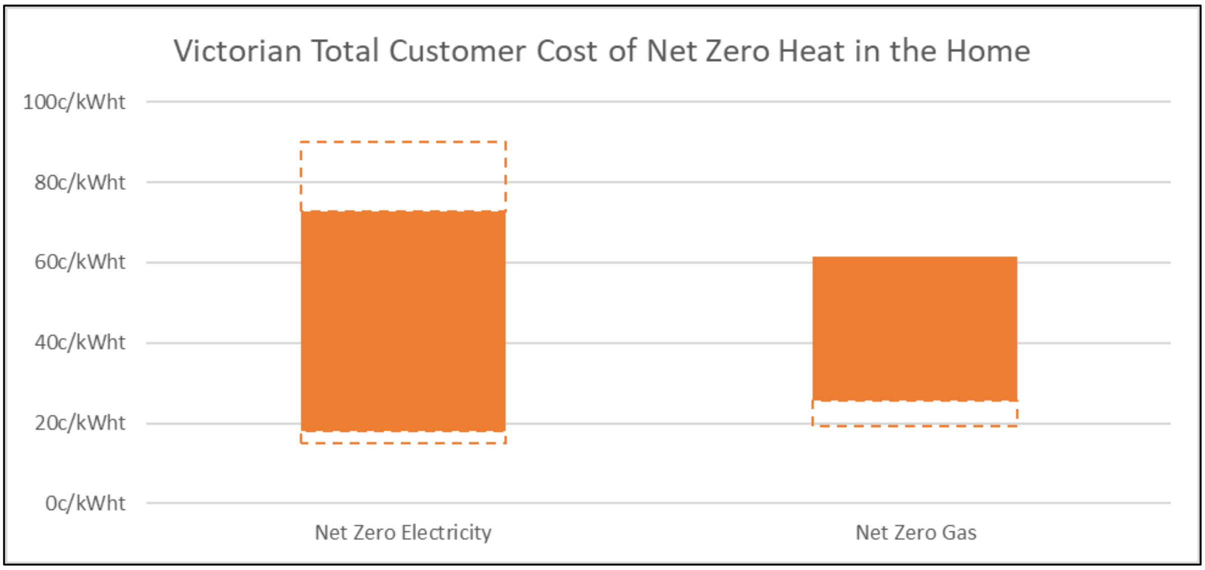

Figure 17: Victorian Customer Cost of Heat in the Home FY2020-21 including Sensitivity Analysis Scenario A, B, C, D and E

4 Observations and discussion

Analysis within Section 3 of the study raise a range of points of observation and discussion. Beyond the necessary conversation around the cost competitiveness of net zero energy pathways for the home and associated implications for policy makers, points of discussion include the diminishing returns of increasing heat pump efficiency, concepts which this study is unable to address, as well as considerations for greater data input to improve the veracity of method outputs.

4.1 Cost competitiveness of net zero pathways

The above analysis predicts that renewable electricity and renewable gas pathways will likely be cost competitive approaches to decarbonising gas use in the home. This is contradictory to the overwhelming rhetoric in the renewable energy community. Decarbonisation of gas use in the home through renewable gas uptake is generally disregarded within this community as in impractical or unaffordable approach relative to the readily available ability to electrify all household energy demand.

One example of this is in the well renowned pro-electrification book *The Big Switch* by Saul Griffith. While the book is ostensibly well meaning in seeking to achieve the least cost net zero Australia, it refers to hydrogen as a "dumb" way of getting to a net zero emission Australia. The book goes on to describe that this position is based upon analysis which considers the energy efficiency of electricity and hydrogen supply chains, concluding that the hydrogen supply chain is the less practical of the two renewable energy pathways because more energy is lost through the hydrogen supply chain.

This analysis demonstrates the shortcoming of concluding that more energy efficient renewable energy supply chains must be more cost effective. It is possible for something to be more efficient and more expensive at the same time. Ultimately, energy customers are more interested in the impact of energy prices rather than the impact of energy efficiency. If an energy pathway delivers a lower cost outcome to a customer despite being less energy efficient, this option will be more appealing regardless of overall energy efficiency (all other factors being equal).

The methodology within this study goes beyond energy efficiency, considering the relative cost effectiveness of comparable renewable energy pathways. By design it tracks the cost of renewable energy supply chains right the way through to the heat that customers seek. More than focusing on the energy efficiency of each supply chain, it focuses on the economic efficiency of each supply chain, for which energy efficiency is just one factor. It is hoped that the outcomes of the examples within this study and subsequent refining of these examples may serve to trigger genuine discussion within the renewable energy sector to consider customer costs of heat as the key metric with which to consider the viability of all renewable energy pathways.

4.1.1 Driving greater retail energy innovation

An added advantage to directly competitive retail renewable electricity and renewable gas pathways is the opportunity for competition between these pathways to spur on innovation within each supply chain. Historically, electricity and gas supply chains have experienced little competition both locationally and between energy forms. The interchangeability achievable between renewable electricity and renewable gas pathways combined with an equivalence of economic outcomes introduces the opportunity for inter- supply chain competition driven innovation. Such competitive tension can help ensure that retail energy costs are continually optimised by private market participants to ensure that the alternate supply chain does not gain an advantage.

4.2 Diminishing returns of higher efficiency heat pumps

The impacts of Sensitivity Analysis Scenarios D and E demonstrate that the first percent of heat pump efficiency above 100 per cent has a greater impact on customer cost of heat compared to the last percent. This makes logical sense considering each successive percent efficiency above 100 per cent is able to reduce the utilisation of an ever-smaller quantity of energy being used. It is not the case that doubling the percentage of heat pump efficiency doubles the reduction in energy use cost. This leads to the need to directly compare bill cost savings through efficiency gains with appliance cost.

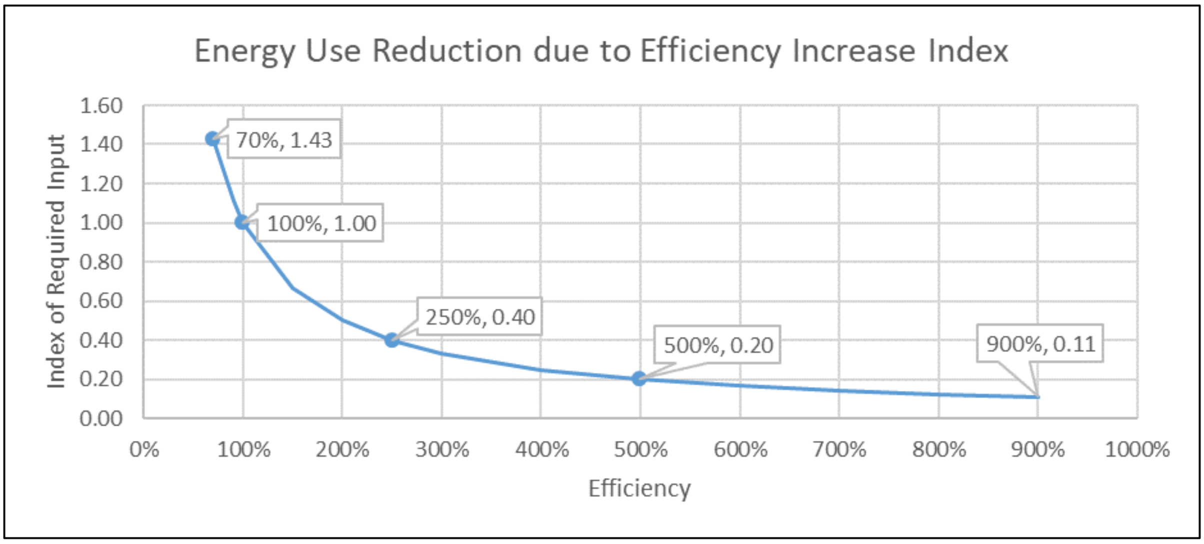

Figure 10: Energy Use Reduction due to Efficiency Increase Index

4.2.1 High efficiency appliances might not deliver lower cost outcomes

The diminishing returns from progressively higher heat pump efficiencies could lead to lower customer cost outcomes being delivered through lower efficiency appliances. Higher efficiency appliances are typically more costly than lower efficiency appliances. The appliance costs used in this study are not for appliance cost alone, hence the highest installation cost may not necessarily be for the highest efficiency appliance. However, assuming that the highest appliance cost does correlate to the highest efficiency in this model can help to demonstrate how this may be the case.

Consider the Component Impact on Customer Cost charts in Figure 8 and Figure 15 above. In the Net Zero Pathways case, we see that electric appliance cost impacts customer cost by 13c to 61c while electric appliance efficiency impacts customer cost by -17c to -39c. If the higher efficiency electric appliance (61c) was also the highest efficiency appliance (-39c), the combined customer cost impact of the appliance would be 22c. However, if the lower efficiency electric appliance (13c) was also the lowest efficiency appliance (-17c), the combined customer cost impact of the appliance would be -4c. In this example, the least cost appliance would be the lower cost, lower efficiency appliance.

4.2.1.1 Implications for future net zero electricity supply chains

Beyond the direct economic impacts of customer choices around appliance cost and efficiency, this has significant implications for the future net zero electricity supply chain. Modelling of a net zero electricity supply chain often considers the use of high efficiency heat pumps. However, if low efficiency heat pumps are more economically viable for customers, then more customers may choose to invest in lower emissions heat pumps, substantially increasing the demand on the electricity supply chain as a whole. This may in effect increase the cost of infrastructure needed to deliver increased quantities of renewable electricity, increasing the cost of retail net zero electricity.

4.3 Discussion for policy makers

The majority of household decarbonisation policy preferences electrification of gas demand over gas use decarbonisation through renewable gas uptake. This has been understandable to date considering the imbalance of information relating to renewable electricity and renewable gases. The outcome of this study should change this view and the approach used to determine which decarbonisation options to support through state and federal policy and funding.

The cost competitiveness of renewable gases with renewable electricity demonstrated in this study indicate that policies which preference one over the other are foreclosing on the opportunity to support equally effective, parallel decarbonisation pathways. This in turn slows Australia's progress towards a net zero future. Further, curtailing one cost competitive approach over another curtails customer choice – a curtailment with no basis if both pathways are cost competitive. Unnecessarily curtailing customer choice risks voter disenchantment with decarbonisation policy, further slowing Australia's progress towards a net zero future.

This study is an indication that the approach to how such challenges are analysed needs to change. Too much policy has been founded upon a narrow view of facts about only part of an energy supply chain. Renewable electricity is cheaper than renewable gas to produce, and electric appliances are more efficient. Despite these advantages, this study shows that the customer cost of both electric and gas net zero supply chains, appliances included, are competitive with each other for heat in the home. Cost to customer needs to be referenced as a decision-making metric over cost of any individual stage of a supply chain in order to avoid missing the wood for the trees of the complex energy transition landscape.

Lastly, the possibility that lower cost, lower efficiency appliances may be the more economically viable choice for electricity customers highlights a need for policy makers to ensure a full range of potential energy efficiency futures are considered within electricity supply chain analysis.

4.4 Concepts which this method is unable to address

The method proposed within this study is unable to address a handful of important questions about a future renewable energy system which combines renewable electricity and renewable gas supply chains.

4.4.1 Relative value of combined renewable electricity and gas systems

The existing energy system has evolved to contain multiple energy pathways due to a natural process of economic evolution. Where one system isn't able to provide the least cost solution, an alternate system prevails, and each energy system has been allowed to support the other in various ways. This is seen in the combination of gas and electricity both being used by individual customers economy wide, and in the use of gas to generate electricity. This study has been undertaken considering that aside from the transition to renewable energy supply chains, all else remains equal.

Most studies which consider a future renewable energy supply chain are unable to articulate the value of combined renewable energy supply chains because this is difficult to model. While the method posed within this study also cannot determine the value of system coupling specifically, this is instead because system coupling is inherently built into the methodology. Being based on existing energy supply data, the value of the coupled electricity and gas system of today is baked in with no perceivable way of separating this value out.

This raises a question of whether a method which inherently includes sector coupling is a sufficiently conservative approach to modelling future energy supply outcomes for customers. This question comes down to whether it is reasonable to consider that future coupled renewable electricity and renewable gas systems would have equal or greater levels of interconnection. If future levels of interconnection and anticipated to be equal or greater, then this model would be conservative as coupled energy system costs would be lower while electricity only system costs would likely be higher.

Luckily, a future combined energy system can be expected to have greater interconnection than the energy system of today. Existing coupling points between the existing electricity and gas supply chains have the opportunity to be added to by power to gas infrastructure in the hydrogen sector. This can lead to greater interconnection between the systems, hence a greater ability for each system to support the other system when required. In the absence of some form of market failure, this can be anticipated to result in reduced overall energy system cost.

4.4.2 Impact of customer preference

This method only considers customer cost; however, customer cost is only one factor in customer preference. Factors such as preferred technology and customer inertia can result in customers behaving counter to their best economic interests. This can result in a reluctance to change appliances, or a preference to change appliances, both regardless of the best economic outcome for the customer. This is especially the case for appliance change opportunities during emergency appliance repair. An interesting case study of this can be seen within the Brisbane residential gas market.

As seen in Figure 2, Brisbane retail gas prices are around double that of the east coast average. High prices are predominantly bolstered by increased network costs due to lower per user demand. The low prevalence of gas space heating leads to residential load being typically centred around gas hot water or gas cooking alone. Despite this, Brisbane residential gas customers remain in the market, demonstrating a disconnect between the anticipated behaviour of an econ and the behaviour of actual energy customers.

4.5 Consideration to support greater input data

This study only includes information that is readily available to its authors at the time of writing. The method however is not constrained to only using this data. More accurate information may be available or may become available over time. Additional information may be able to be used to generate a more accurate understanding of the customer cost of heat through this method. The following are a few recognised areas in which greater information could be provided.

4.5.1 Feedback from broader customer and emissions reduction community

There is an opportunity to crowd source information for use within the method proposed in this paper. It is hoped that this method may be picked up by customer advocates, emission reduction advocates, and consultants to form the basis of wider ranging studies on the cost effectiveness of different energy pathways for different customers.

4.5.2 Impact of greater building insulation

A key factor in energy costs is the ability for a home to maintain heat. This study has considered a stable thermal demand in a home; however this value could decrease. Considering an anticipated level of improvement to the average thermal insulation of a home would deliver a reasonable improvement to the accuracy of results derived via this method.

4.5.3 Household batteries

A 40 per cent direct utilisation of solar PV has been considered in Sensitivity Analysis Scenario A. This percentage was chosen so that the study would not have to go to the rigour of costing household battery utilisation costs. Future use of this method could consider reasonable estimates of the levelized cost of household solar PV plus battery storage in order to consider the impact on customer cost of electricity supply. In doing so, care would need to be taken to not completely remove the network component of electricity costs noting that households are not anticipated to completely disconnect form the grid when installing batteries.

4.5.4 Additional impact of the electrification of vehicles

Gas demand is not decarbonising alone. Electrification of vehicle energy demand is anticipated to greatly increase household electricity demand and risks greater volatility within suburban electricity distribution systems. The combination of these parallel transitions could have an impact on the customer cost of electrification of gas demand in the home.

This study considered zero increase in customer cost of electricity distribution infrastructure in order to ensure a conservative approach to addressing the potential for electricity distribution cost increases. Higher resolution retail energy price breakdowns would be required to consider the impact of differing electricity distribution costs as a result of combined residential vehicle and gas use electrification as these are currently combined with electricity transmission costs to form “Network Costs” within the AER datasets.

5 Conclusion

The methodology proposed within this study represents an approach to modelling the customer cost of heat for a range of customers in either current or future energy cost scenarios. The application of this method to the customer cost of heat in the home demonstrates the value of full supply chain analysis all the way to customer cost of heat. The study identified why gas is more cost effective for freestanding homes in FY2020-21 as well as the potential for renewable gases to deliver lower customer cost of heat in the home in a net zero future.

Founding the study in AER data works in the existing economic balance of wholesale, infrastructure and retailing costs for each energy supply chain as well as the value of the integrated electricity and gas systems of today. Building upon this basis with data that can be added to and changed over time allows this method to maintain relevance as time progresses and technologies evolve.

Beyond observing that renewable gases are cost competitive with renewable electricity in delivering net zero heat in the home, the method demonstrates the importance of appliance cost over appliance efficiency, and the importance of both over wholesale and retail energy costs. Until electric heat pump appliances can achieve installed and rectified costs in line with that of gas or hydrogen appliances, the benefit of their efficiency gains is marginally impactful at best.

Policy makers can take away two important learnings from this study. First, that a net zero gas supply chain can deliver cost competitive heat in residential homes compared to renewable electricity. This means that any policies that preference electric appliances over gas appliances, or seek to disrupt gas connections, are acting in opposition to the least cost, most rapid gas use decarbonisation pathway for Victoria. Such policies should be replaced with policies which provide funding for high efficiency hydrogen ready gas appliances or supporting renewable gas production through a renewable gas target. Such policies would cost less and duplicate the State's future renewable energy pathways.

Second, policy makers can take away an understanding that it is the customer cost of heat that matters when determining the most cost-effective net zero energy pathway. Greater efficiency or affordability of any one part of a supply chain does not matter to customers if the entire supply chain costs them more than its alternative. Policy makers risk funding less economically efficient decarbonisation pathways if customer cost of heat is not considered, spending more government money on lower emissions reduction. Policy makers have an opportunity to ask for the right data, the data that matters to customers, data about customer cost of heat.

Finally, this methodology paper has been developed in the hopes that others interested in least cost energy decarbonisation may use it as well. For the avoidance of doubt, the authors of this study offer an unrestricted global licence to utilise the intellectual property contained within this paper to any reader. It is hoped that through a greater understanding of the impact of entire energy supply chains on customer cost of heat we will be able to achieve a broader understanding around the wide range of renewable energy options available to support Australia's least cost, most rapid transition to net zero emissions.