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Climate mitigation and adaptation in the ACT: costs, benefits and implications

Final report

Environment, Planning and Sustainable Development Directorate

22 February 2018 | 5157

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Executive summary

This report analyses various measures under consideration by the ACT Government to address climate change through reducing greenhouse gas emissions (mitigation) and preparing for the physical impacts of climate change (adaptation). Mitigation measures are assessed against the 2030 emission reduction target range for the ACT recommended by the ACT Climate Change Council, which is 65-75 percent below 1990 levels.

Key findings

In summary, the key findings of this report include:

- Modelling of emissions reduction measures indicate sufficient abatement to meet the 65 percent target at an average cost of $31.95 per tonne.
- Priority measures are those that address transport emissions through electrification, and replacement of gas equipment with electric equipment for space and water heating. These provide substantial volumes of abatement at reasonable cost.
- A key supporting measure is maintenance of the ACT's 100 percent renewable electricity supply, which enables electrification of transport and heating to achieve zero-emissions outcomes. Assessment of two different demand forecasts suggests it is uncertain as to whether the ACT will need to access additional renewable energy supply by 2030, but we find no additional cost to the ACT in covering the potential shortfall identified in our revised reference case, due to the trends toward equivalence of renewables prices and wholesale electricity prices in the National Electricity Market.
- Modelling suggests the 75 percent target will be significantly more challenging or costly to achieve, as it requires either additional, unmodelled measures, or a significant reliance on land-based sequestration outside the ACT. Depending on the degree of reliance on the land sector, the average cost could range from $8.40-126.00 per tonne.
- Abatement costs are important but should not be considered the sole criterion for measure selection. Some measures have low direct abatement costs but significant economic implications, and may therefore face challenges in translation to policy and implementation. For example, more stringent standards for building energy performance could have a number of flow-on impacts, depending on how they are implemented: on the cost of housing construction, which is a major economic driver, or on the location of housing construction, which could leak to neighbouring jurisdictions with lower standards.
- Conversely, some measures have high abatement costs but potentially significant co-benefits and adaptation benefits. Building retrofits, if targeted at particularly poorly performing homes and/or particularly vulnerable households, could produce significant benefits to residents via lower bills, improved comfort, health and heat stress prevention. Similarly, increasing urban canopy cover offers a limited amount of abatement at high cost – but also provides adaptation benefits through cooling, and other important co-benefits in terms of pollution reduction, increased biodiversity and higher amenity values.
- It is important to note that the costing of measures is based on currently available information. Many costs are likely to change significantly over time in response to changes in technology, markets, consumer behaviours and business models. Moreover, the modelling we have undertaken cannot capture all of the flow-on consequences, both positive and negative, of each measure.

The ACT can achieve the 65 percent target at an average cost of $31.95 per tonne

The greenhouse gas emissions of the Australian Capital Territory (ACT) in 2030 in a business-as-usual or reference scenario are 1300 kilotonnes of carbon dioxide equivalent (ktCO_2-e). The ACT Climate Change Council's recommended emissions reduction targets for 2030 are 65-75 percent below 1990 levels, or to 799-1119 ktCO_2-e. To achieve the 65 percent target, the 2030 abatement task is therefore 181 ktCO_2-e and to achieve the 75 percent target, the abatement task is 501 ktCO_2-e.

Table E1: ACT emissions in 2030 and abatement tasks for recommended targets

Scenario	2030 emissions	Abatement task from revised reference case (ktCO_2-e)
Original reference case[1]	1279	-
Revised reference case used in this analysis	1300	-
65 percent reduction from 1990	1119	181
75 percent reduction from 1990	799	501
Measures modelled so far excluding land sector measures within and around ACT		258

Measures to reduce ACT emissions have been modelled by Energetics and Cadence Economics following discussion and selection with the Environment, Planning and Sustainable Development Directorate (EPSDD). The measures are assessed in terms of their costs, impacts and benefits, with particular focus on the cost of abatement ($/t$CO_2$-e) and volume of potential abatement in 2030 (ktCO_2-e). Abatement costs are expressed both in terms of private costs (to the entity required to undertake the emission reduction action) and welfare costs (the net cost to the ACT economy). Table E2 outlines the average costs of achieving these targets. The individual measures modelled are summarised in table E3 below.

The total volume of abatement from measures excluding the land sector is 257.7 ktCO_2-e. This is more than enough to achieve the 65 percent target, which can be reached at an average welfare cost of $31.95 per tonne.

Achieving the 75 percent target requires access to carbon sequestration in the land sector, which has risks

The volume of abatement achieved through these measures is, however, 243 ktCO_2-e short of the 75 percent target. If measures to sequester carbon in the land (inside and within 100 km of the

[1] The 'original reference case' is from an earlier projection of ACT emissions produced by Point Advisory for the ACT government in October 2017. Minor updates and adjustments have been made to it to produce the revised reference case used in this analysis. See section3.

ACT) are used to meet this 243 ktCO_2-e shortfall, the 75 percent target can be reached at an average welfare cost of $126.00 per tonne. Greater use of land-based sequestration to meet the target could produce a lower average abatement cost by replacing some of the higher-cost abatement measures with more afforestation outside the ACT. However, the ACT Climate Change Council has recommended against a reliance on land sector offsets because carbon stored on land is vulnerable to being returned to the atmosphere.[2]

Table E2: Average private and welfare costs of achieving emission reduction targets

Target to be achieved	Average welfare cost ($/tonne)
Achievement of the 65% target	$31.95
Achievement of the 75% target (top up with land sector abatement)	$126.00
Achievement of the 75% target (exclude higher cost measures and use more land sector abatement)	$8.40

Table E3: Emission reduction measures – costs and volume of abatement

Measure	Action	Private cost of abatement ($/tonne)	Welfare cost of abatement ($/tonne)	Volume of abatement in 2030 (ktCO_2-e)
Accelerated replacement of gas space heaters	Replacement with room heater 5 years before end of life	$11.61	$9.61	11.8
	Replacement with ducted heater 5 years before end of life	$16.61	$12.82	12.5
Replacement of gas water heaters	Upgrade to solar hot water systems	$41.34	$32.85	30.1
	Upgrade to heat pump storage systems	$238.66	$189.06	30.1
Improvements to building energy efficiency	Retrofits to the building shell of existing houses	$1,564.31	$1,241.73	37.0
	More stringent building energy standards for new residential buildings	$0.00	$0.00	5.4
	More stringent energy standards requirements for new commercial buildings	$0.00	$0.00	12.0

[2] *http://www.environment.act.gov.au/__data/assets/pdf_file/0004/1135876/20171019-Letter-from-ACT-Climate-Change-Council-to-Minister-Rattenbury-interim-targets.pdf*

Increase uptake of electric vehicles (EVs)	Provide public access to EV charging stations	$69.00	$38.75	27.5
	Use EVs in ACT government fleet	$1548 (2020) to -$470 (2025)	$869.33 to -$263.95	1.6
	Electrification of ACT bus fleet	-$81.25	-$45.49	34.7
Increase uptake of public /active transport	Achieve an additional 2 percentage point mode shift to public transport above 'Transport for Canberra' target	$86.55	$94.93	23.4
Reduce solid waste emissions	Compost residential food and garden organics	$75.00	$11.71	7.2
Carbon sequestration through land use change	Increase urban canopy cover within ACT	$626.12	$351.62	12.8
	Increase afforestation and reforestation within 100km of ACT	$25.00	$14.04	More than sufficient for target range
Maintain 100 percent renewable energy supply	Purchase additional renewable energy to prevent shortfall in renewable energy supply (if required)	$0.00	$0.00	26.0

Both mitigation and adaptation measures have multiple additional benefits

Energetics and Cadence Economics also examined two broad categories of climate adaptation measures. These have not been assessed quantitatively, as further research and policy development is required to make robust quantitative analysis. However, these adaptation measures, as well as the emissions reduction or climate mitigation measures outlined in Table E3 above, can be expected to produce benefits that can be quantified.

Table E4: Adaptation measures considered

Objective	Measures
Heat stress prevention	Climate oasis - conversion of nominated locations in each suburb for relief by community during heatwaves
	Decrease urban heat island effect by use of green walls and roofs in town centres/urban intensification areas
	Cooling town centres with increased use of watered grass, removal of paving, and greater density of summer shade trees

Storm protection	Stormwater capture from side entry pits with subsurface distribution to reduce flash flooding, increase water vegetation, decrease pollutants in waterways
	Stormwater capture and use; permeable pavements; high albedo &/or low thermal mass surfaces

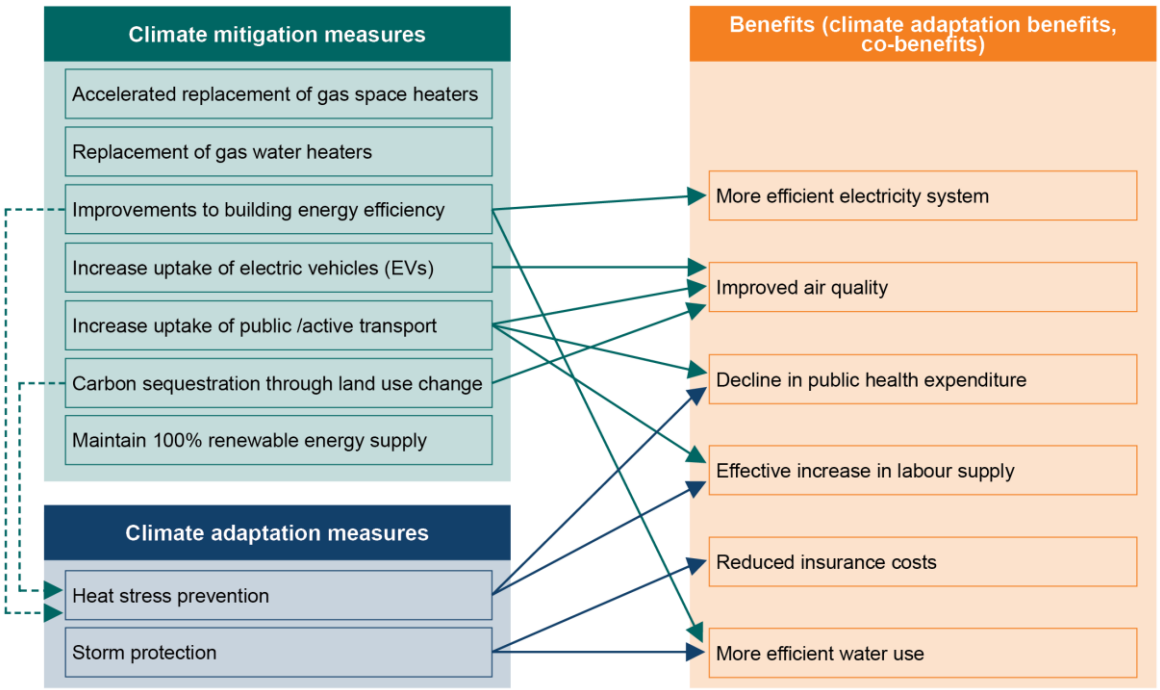
The relationship between climate mitigation and adaptation is multifaceted. Some actions have both mitigation and adaptation benefits – such as tree planting to reduce urban heat island effects, which also sequesters carbon.

A broad definition of an adaptation benefit includes any outcome that increases the capacity of a community to cope with the challenges of climate change. Under this definition, adaptation benefits can include outcomes that are not directly related to the physical impacts of climate change. A narrower definition of adaptation might require that the purpose of an action is specifically to address the impacts of climate change. Benefits resulting from mitigation measures that happen to improve community capacity and resilience would then be defined as co-benefits.

Quantifying these benefits is complex but can reveal significant value

These complex relationships make it challenging to capture the interplay between climate mitigation and adaptation actions and outcomes. However, some causal relationships can be recognised in economic modelling. Figure E1 outlines the causal connections between climate mitigation and adaptation measures and a range of measurable adaptation or co-benefits.

Figure E1: Causal relationships between climate mitigation and adaptation measures and adaptation /co-benefits



Examples of these relationships include:

- **Energy efficiency and electricity systems**: Improving the energy efficiency of buildings improves passive thermal control, reducing peak loads for heating and cooling. Reducing the

gap between peak and base demand levels on electricity networks reduces the need for 'gold plating' of infrastructure, improving the productivity of the capital stock in electricity networks.

- **Electric Vehicles and Air quality:** Increased uptake of electric vehicles reduces aggregate emission of (for example) NOx, SOx and particulates from the vehicle fleet.
- **Public/Active transport and Increased labour supply:** Switching from cars to active transport improves public health through (for example) improved individual cardiovascular fitness, reducing the load on public health facilities Increased levels of physical activity have been shown to improve labour market outcomes, both through increased levels of labour force participation rates and reduced illness.
- **Heat stress prevention and Public health expenditure**: Heat stress can be a significant health concern for people in general; even more so for vulnerable individuals such as the elderly and the young. Preventing or reducing levels of heat stress can reduce the load on the public health system with subsequent reductions in expenditure.
- **Storm protection and reduced insurance costs**: If a region is better protected against extreme outcomes such as flash flooding this will be captured by lower insurance premiums.

Attention to adaptation and co-benefits in policy design can help achieve cost neutrality across the spectrum of climate change policies

It may be possible to achieve cost neutrality across the full range of ACT climate policies. This is dependent both on the direct cost savings through (for example) improved energy efficiency and through the cost savings that might be achieved through adaptation and co-benefits.

The links between the cost of mitigation strategies and the extent to which these strategies can drive benefits are in general not well quantified. In the absence of available bottom-up or actuarial analysis linking measures with benefits, this break-even analysis can guide qualitative analysis and provide insight as to where future investigation and policy development may be most effective.

For each individual adaptation or co-benefit to offset the entire cost of achieving the 65 per cent target, ACT would require in direct terms:

- 19.25 full time equivalent employees to either avoid sickness due to heat-related illness or through improved health (e.g. through active travel)
- Avoid $17.31 million in health expenditure
- Save $12.24 million in insurance costs
- Improve water system productivity by $7.41 million
- Improve productivity of the electricity network by $6.11 million

Box 1. Considering the Social cost of carbon

The ACT Climate Change Council has recommended to the ACT Government that the social cost of carbon (SCC) be applied in any cost-benefit analyses used to inform public investments or policy and regulatory decisions in the ACT. The SCC represents an estimate of the global economic damage caused by each additional tonne of CO_2-e emitted into the atmosphere in a given year. Future costs are discounted to represent what society should be willing to pay in the present.

The SCC recommended by the Climate Change Council is based on the United States SCC.[3] Because of methodological inconsistencies between the US SCC and Australian approaches to benefit-cost analysis, comparing the costs of abatement in this report with the SCC should be

[3] Revesz, R. et al., 2017. 'Best cost estimate of greenhouse gases', *Science* 357(6352): 655, referenced in ACT Climate Change Council, Letter to Shane Rattenbury MLA, 19 October 2017.

done with caution (see section 8 for more details).

Nonetheless, as the current best standard for economic analysis of the damages of climate change, the SCC is a useful concept. The ACT Government may wish to consider developing an ACT-specific SCC or an alternative approach to valuing emissions reductions.

Recommendations

- We recommend some priority areas for further research:
  - Development of methodologies relevant to the ACT to assess health outcomes associated with specific climate mitigation and adaptation measures, such as investment in active transport and building energy efficiency
  - Development of a robust evidence base on industry learning rates driven by building energy efficiency standards to inform development of policy on building energy efficiency standards
  - Investigation of the impacts of building energy efficiency on electricity system productivity
  - Development of an ACT-specific social cost of carbon or alternative approach to valuing emissions reductions for use in policy development.
- We recommend facilitation of electric vehicles uptake as the highest priority area for further policy development and implementation:
  - The potential for electrification of transport to enable deep decarbonisation of the ACT economy is unmatched by emission reduction opportunities in any other sector. While we find that the amount of abatement from private EVs uptake in 2030s is not large (27 ktCO_2-e), it reflects change of a significant share of the ACT vehicle stock: from EVs constituting less than 1 percent of ACT vehicles currently to 15 percent by 2030. The share of EVs can be expected to grow much further in the 2030s, enabling rapid reductions in transport emissions through that decade.
  - While it is widely expected that nearly all vehicles will be EVs eventually, the speed of this transformation is highly uncertain.
  - The expected cost competitiveness of EVs within a decade gives the ACT Government a useful timeframe to develop an EV strategy that includes the measures analysed in this report.
  - As the upfront costs of EVs are likely to reach parity with conventional vehicles in this time, tackling other potential barriers to EV deployment, such as range anxiety and lack of consumer knowledge, will be necessary to maximise voluntary uptake of EVs.
  - Electrification of ACT government vehicles and the bus fleet has benefits beyond direct emission reductions, such as increasing the visibility of EVs in the territory, providing consumer experience of electric vehicles, and providing demand for a charging network and electric vehicle models. A further potential benefit is in contributing to the reputation of the ACT as a hub for electric vehicle research. All of these benefits suggest that the ACT may not wait until EVs are cheaper than conventional vehicles to make the switch, but should weigh the additional benefits accrued by demonstrating leadership against the extra costs of investing in EVs while they still maintain a cost premium.
  - A further benefit of choosing early rather than late investment in EVs is that the ACT will be more likely to be ready to make the switch to EVs if costs fall faster than projected.
- Because the transport sector as a whole is the largest source of ACT emissions in the medium term, a package of measures will be required to decarbonise the whole sector. As the direct and economy-wide impacts of individual transport policies lead to substantial interactions among sub-sectors, we recommend that further development of ACT transport

strategy beyond the current 'Transport for Canberra' commitments include the following elements

- Research to develop and test models of mode shifting among various types of private, public and active transport resulting from changes to costs and services
- Robust modelling of mode shift impacts in terms of consumer behaviour, financial flows and infrastructure needs
- Development of risk assessments and indicators for further technology-induced disruption to the transport sector via advances in mobility-as-a-service and autonomous vehicles.

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Glossary

Abatement: Mitigation of climate change by reducing greenhouse gas emissions

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Afforestation: Planting of new forests on land which, historically, has not contained forests

CEGEM – **Cadence Economics General Equilibrium Model**: Cadence Economics' in-house CGE model

CGE – **Computable General Equilibrium**. A widely used class of economic models that address key shortcomings of Input Output analysis, and allow for economy-wide assessment of a range of policy and project interventions

CO_2 – carbon dioxide: the greenhouse gas principally responsible for climate change

CO_2-e – carbon dioxide equivalent: a measurement of greenhouse gases' different global warming potentials that allows for the conversion of non-CO_2 gases to equivalent units of CO_2.

Co-benefit: A benefit of a climate mitigation or adaptation effort that is additional to the direct objective of the effort

Discount rate: The rate at which future costs and benefits of an investment are converted to present values in recognition of the opportunity cost of the investment, whether this is the cost of delaying consumption or the alternative investment opportunities forgone.

Economic welfare: the overall level of prosperity and standard of living within an economic system.

GRP – Gross Regional Product: The regional equivalent of the national measure Gross Domestic Product. In this report the relevant region is the ACT.

GRI – Gross Regional Income: The regional equivalent of the national measure Gross National Income. In this report the relevant region is the ACT.

GTAP – Global Trade Analysis Project

GWh – Gigawatt hour

MWh – Megawatt hour

Mitigation: Activity to limit global temperature rise by reducing greenhouse gas emissions and enhancing greenhouse gas sinks

Private costs: The cost of a measure to the entity on which the measure is imposed

Reforestation: Establishment of forest on land that had recent tree cover

RET – Renewable Energy Target

SCC – social cost of carbon: An estimate of the global economic damage caused by each additional tonne of CO_2-e emitted into the atmosphere in a given year, with future costs discounted to represent what society should be willing to pay in the present

Welfare costs: The total (that is, direct and indirect) cost of a measure as measured through an appropriate economic welfare metric such as GRI.

1. Purpose of this report

The Government of the ACT is currently developing strategies to reduce the territory's greenhouse gas emissions and successfully adapt to climate change impacts. The ACT Government has already taken significant steps in this regard, with the implementation of policies to achieve 100 percent renewable electricity by 2020 and a commitment to net zero emissions by 2050 at the latest. The development of mitigation and adaptation strategies reflects the ACT Government's commitment to ongoing leadership in climate action.

This report discusses the results of analysis of further measures being considered by the ACT Government to reduce greenhouse gas emissions and adapt the territory to the impacts of climate change.

Each measure has been analysed in terms of its potential costs, impacts and benefits, to the extent possible on the basis of available information. Where data on costs and benefits is lacking, potential costs and benefits are discussed with a view to guiding further research and policy development. Also discussed is the capacity of the emissions reduction measures, singly and in combination, to achieve the 2030 targets recommended by the ACT Climate Change Council of reducing emissions by 65-75 percent below 1990 levels.

This analysis builds on work already undertaken for the ACT Government, which examined policies and strategies to reduce emissions across stationary energy, transport, waste, and the land sector. The reports and data prepared for the ACT government that are drawn on in this analysis and referenced in this report include:

- "ACT Transition to Net Zero Emissions – Stationary Energy/Buildings", Strategy. Policy. Research, September 2017 [**the Stationary Energy Report**]
- "Past and projected future components of electricity supply to the ACT, and resultant emissions intensity", Dr Hugh Saddler, April 2017.
- "Strategic Options for Reducing Emissions in 2030, 2040 and 2050", AECOM, August 2017 [**the Transport Report**]
- "Pathway report ACT 2050 emissions modelling – waste sector", Point Advisory, June 2017 [**the Waste Report**]
- "Pathway report ACT 2050 emissions modelling – land use", Point Advisory, June 2017 [**the Land Use Report (within ACT)**]
- "Reforestation and afforestation opportunities within 100 km of the ACT", Point Advisory, May 2017 [**the Land Use Report (outside ACT)**]
- "1. Final ACT Integrated Emissions Model" [**the Integrated Model**].

Energetics and Cadence Economic have supplemented these reports with our own analysis, in order to:

- More clearly define policy interventions
- Understand and explain the integration of the measures within a modelling framework
- Define the costs of measures to achieve emission reductions in terms of cost of abatement and economic costs
- Discuss co-benefits, risks and considerations with regard to each potential measure
- Discuss options and recommendations for ACT climate policy development and implementation.

The findings of this report are intended to contribute to the development of the ACT's mitigation and adaptation strategies.

2. Structure of this report

Section 3 of this report provides the context of the ACT's projected emissions to 2030 under a business-as-usual or reference scenario, and the consequent level of emissions reductions needed to meet the 65 percent or 75 percent target recommended by the ACT Climate Change Council.

Section 4 outlines each mitigation measure considered, and provides an explanation of how its cost of abatement per tonne has been calculated.

Section 5 discusses the broader economy-wide impacts of each modelled mitigation measure.

Section 6 examines the adaptation measures proposed by the ACT Government and considerations in assessing their impacts, while section 7 outlines the relationships we have identified between mitigation and adaptation measures and adaptation benefits.

Section 7 discusses how adaptation benefits could offset mitigation costs to achieve a cost-neutral climate policy framework.

Section 8 discusses application of the social cost of carbon to cost-benefit analysis.

Key findings, implications and recommended next steps for the ACT Government are provided in section 9.

3. The situation in 2030

3.1. Greenhouse gas emissions and the abatement task

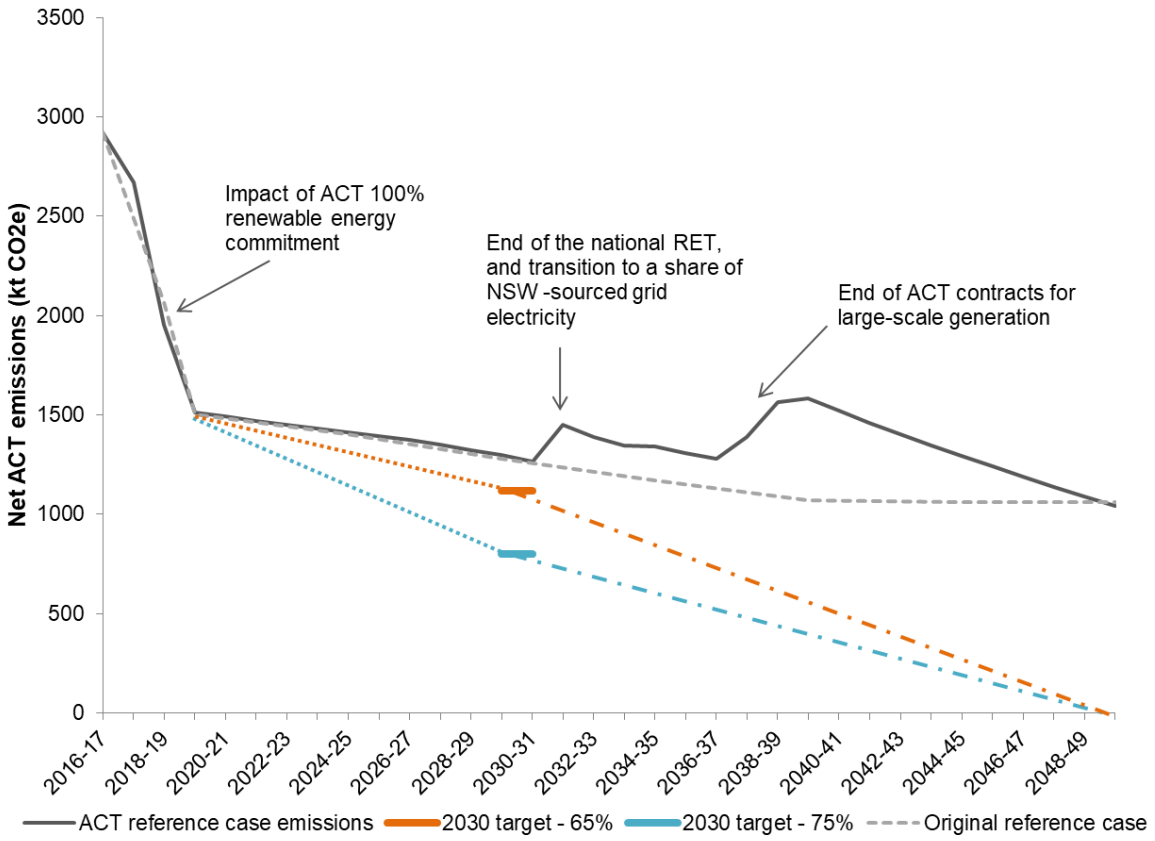
We calculate that ACT emissions in 2030 in a business-as-usual (BaU) or reference scenario are 1300 ktCO_2-e. Our estimate of emissions included the following adjustments relative to the reference case in the Integrated Model:

- An increase in the BaU uptake of electric vehicles (EVs**)** reflecting developments in EV technology and market projections compared to the data used in the Transport Report.
- A revision of the BaU uptake of rooftop solar photovoltaic (PV) systems in both the residential and commercial sectors. Our analysis considers that the economics of rooftop solar PV and distributed (household) battery storage will drive the adoption of solar PV to the point where by 2030 around 20 percent of available roof space will be utilised for solar PV. The rise of building-integrated solar PV will further promote this trend.
- Minor emissions from the consumption of electricity, which reflected a slight shortfall in renewable electricity from 2025 due to the impact of the electrification of transport. We recognise that the ACT's policy is to maintain 100 percent renewable energy, and options to do this are discussed in section 3.2 The Electricity Balance.

The 2030 targets recommended by the ACT Climate Change Council targets in 2030 are to reduce emissions by 65-75 percent below 1990 levels. To achieve the 65 percent target requires ACT

emissions in 2030 to be no more than 1119 ktCO_2-e. Achieving the 75 percent target requires ACT emissions in 2030 to be limited to 799 ktCO_2-e. The abatement task for the 65 percent target is therefore 181 ktCO_2-e, while the 75 percent target requires abatement of 501 ktCO_2-e. This indicates that significantly more emission reductions – and therefore more and/or stronger measures – are required to achieve the 75 percent target. However, reaching the 75 percent target means that the trajectory toward net zero emissions by 2050 can be less severe, as indicated in the figure below.

Figure 1: ACT greenhouse gas emissions to 2050[4] and recommended targets



Certain features of the reference case are worth highlighting:

1) The rapid fall in emissions to 2020 reflects the implementation of the ACT's 100 percent renewable electricity commitment.
2) The reduction in emissions in the period from 2020 to 2030 results from the installation of cost effective solar PV and the start of the electrification of heating and of transport.
3) The major diversion from the original reference case[5] reflects the original reference case's assumption that ACT would maintain sufficient renewable energy supply for its electricity demand out to 2050. In our reference case we do not make this assumption. The national Renewable Energy Target ends in 2030 and we have assumed that it is not replaced. However, wind and solar will be the lowest cost forms of power generation, and in the period after 2030 the retirement of most of the large coal-fired power stations in the NEM will occur which means that renewable generation will increase even in the absence of either national policy intervention or new ACT policies to maintain 100 percent renewable electricity.

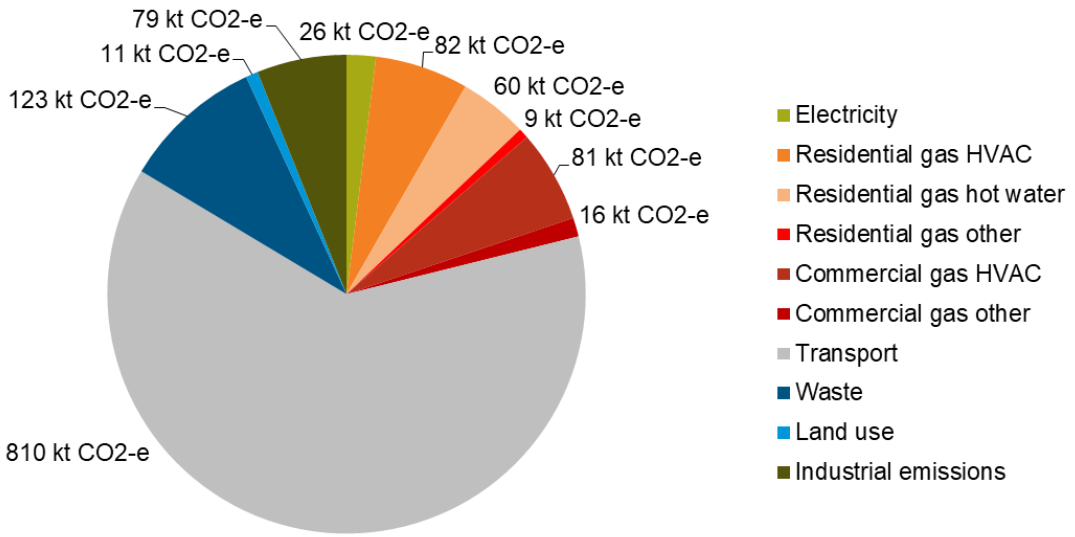
[4] Unless otherwise noted, the source of the information in the figures is Energetics and Cadence analysis.
[5] The 'original reference case' is from the Final ACT Integrated Emissions Model, an earlier projection of ACT emissions produced by Point Advisory for the ACT government in October 2017.

4) The general fall in emissions after 2030 reflects the on-going adoption of rooftop solar PV and the rapid decarbonisation of the NSW grid[6]. The hump in emissions in the late 2030s reflects the expiry of the ACT's existing 20-year feed-in-tariff contracts for large-scale renewable generation.

All of these factors reflect the significant changes underway in electricity generation. Because the ACT is already well on the way to achieving net zero emissions electricity, the largest source of emissions in 2030 will be the transport sector, which is projected to be responsible for nearly two-thirds of the ACT's emissions – 810 ktCO_2-e. Residential and commercial gas consumption – for space heating and cooling, water heating and other uses – produces another 250 ktCO_2-e (see the red and orange wedges representing gas-using activities in Figure 2). The waste and industrial sectors are responsible for, respectively, 123 and 79 ktCO_2-e.

Given its contribution to emissions in 2030 and beyond, abatement efforts need to target the transport sector. The bulk of transport emissions are produced by private, light vehicle use (cars) so the most important abatement measures are likely to be those which address this source. Natural gas use in the built environment is also an important emissions source, and measures that reduce the use of natural gas must also be considered. As the key option to reduce transport emissions and natural gas use is electrification (of vehicles and space and water heating, respectively), the impact on electricity demand, and therefore the potential for increasing electricity emissions must therefore also be considered.

Figure 2: Emissions in 2030 by source

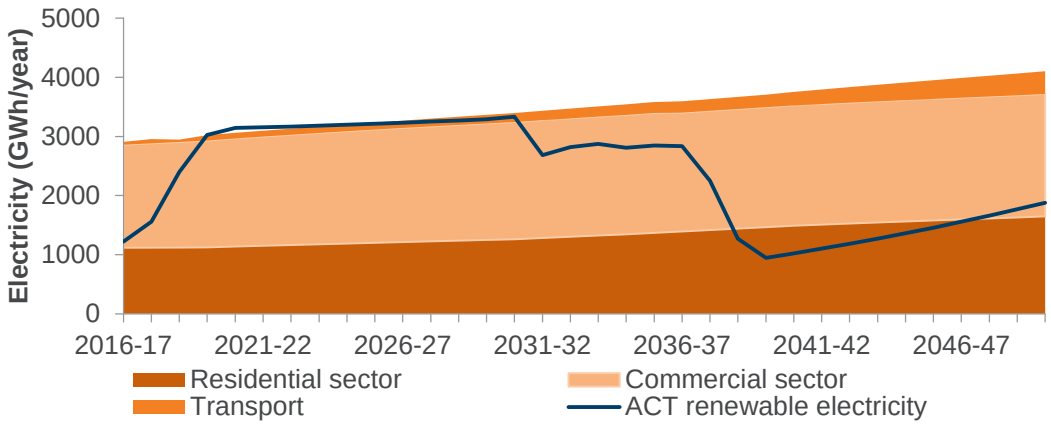


[6] Some coal-fired generators have already indicated an expected date of closure – for example, Origin Energy has stated that Bayswater power station in NSW will close by 2035. Most other generators have not given a firm exit date, but even if each station were to keep operating for 50 years from its commissioning, Vales Point B, Bayswater and Eraring in NSW, Yallourn and Loy Yang A in Victoria, and Gladstone and Tarong in Queensland would all close by or before 2035. See illustrative coal generator retirement patterns in COAG Energy Security Board, Health of the National Electricity Market, 2017 ***http://www.coagenergycouncil.gov.au/publications/health-national-electricity-market-report*** and Investor Group on Climate Change, 2017. *Coal, Carbon and Community*, ***https://igcc.org.au/wp-content/uploads/2016/04/Coal-Carbon-and-Community.pdf***

3.2. The electricity balance

ACT Government policy is to maintain an electricity supply that is sourced from 100 percent renewable energy. Our projection of the territory's emissions finds that by 2030 electricity demand overshoots the territory's projected renewable energy supply by approximately 2 percent (75 GWh, roughly equivalent to 10,500 households[7]). Figure 3 shows the relationship between the demand for electricity and the renewable supply.

Figure 3: The electricity balance – electricity demand versus renewable supply



The transport category refers to BaU growth of electric vehicles. This makes up a very small but steadily growing source of demand, reaching 146 GWh by 2030. Policies that support the additional uptake of EVs will further increase the demand for electricity. The rapid falls in the renewable supply occur at the end of the RET, when the accounting for renewable electricity changes and during the period when the feed-in-tariff contracts come to an end.

[7] Based on representative household consumption of 7,151 kWh/year. AEMC, Retail electricity price trends 2017. ***http://www.aemc.gov.au/News-Center/What-s-New/Announcement-Documents-(non-project)/EPR0056-Australian-Capital-Territory-fact-pack-and.aspx***

The sources of electricity in 2030 can be seen in Figure 4. "National LRET" refers to the ACT's share of the generation built under the federal Large-scale Renewable Energy Target, and the ACT's share of pre-LRET renewable energy. "ACT reverse auctions" refers to the large-scale wind and solar generators built as a result of existing ACT Government policy. "ACT solar PV pre-2020" represents the output of rooftop solar PV in the ACT, installed during the period of the national Small-scale Renewable Energy Scheme. "ACT solar PV post-2020" shows solar PV installed after the SRES stops growing in 2020. The small volume of NSW electricity that makes up the balance results in emissions of 26 $ktCO_2$-e.

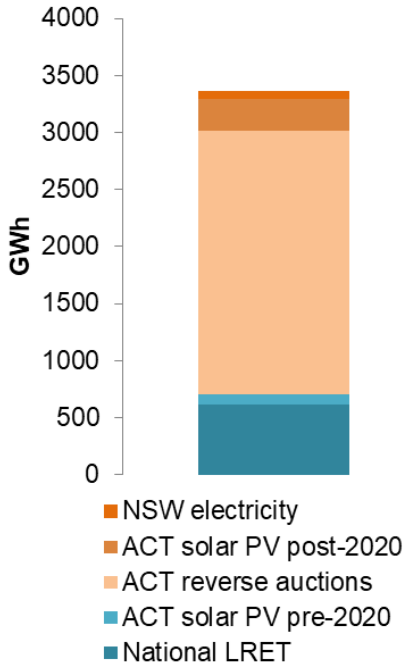


Figure 4: Where the electricity comes from in 2030, in the absence of new efforts by the ACT to achieve 100 percent renewable electricity

This has several implications:

- The ACT may need to contract for an additional 75 GWh of renewable electricity in 2030, in order to maintain a 100 percent renewable supply.
- Measures that drive further electrification will increase electricity demand, and result in higher emissions and/or the need for additional purchases of renewable energy.
- Alternatively, measures that reduce electricity demand by 75 GWh can enable the ACT to stay within its projected renewable energy supply. However, demand reduction measures do not have a direct emissions reduction impact in the context of a 100 percent renewable electricity supply.

The level of uncertainty over projected electricity demand is considerable, and we believe it is also plausible that demand will be significantly less than projected. For example, an alternative forecast for lighting (see Appendix A) finds that the supply of renewable electricity exceeds the ACT's demand in 2030 by about 140 GWh. In this alternative forecast, there is more than enough renewable energy supply, and reference case emissions in 2030 would be 26 $ktCO_2$-e lower. In this context, the electrification of passenger vehicles could double without the need for extra renewable energy. We discuss reasons why trends in lighting are likely to reduce electricity demand in Appendix A.

Several options are available to balance the demand for electricity and the supply of renewable electricity. These include:

- Purchase or finance the construction of new renewable generators. This is likely to have zero to minimal additional cost compared with the alternative (purchase of NSW grid electricity): renewable electricity prices are likely to be similar to prices in the National Electricity Market as forward prices in the 2030s will be set by lowest cost new entry technologies, which are solar and wind.[8]
- Encourage measures to reduce electricity demand. These will only have an abatement value to the extent that they prevent demand exceeding renewable supply.

[8] http://aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/EFI/Jacobs-Retail-electricity-price-history-and-projections_Final-Public-Report-June-2017.pdf

- Offset any residual electricity emissions with land sector abatement at a projected cost of \$25/tCO_2-e (see section 4.2.6 below).

As we have outlined in Appendix A, policy and technology developments in the uptake of LED lighting at zero or a marginal cost could cover any potential shortfall in renewable electricity. However, as our emissions forecast includes 26 ktCO_2-e resulting from a shortfall in renewable electricity, we have included in the abatement measures an additional measure reflecting the purchase of additional renewable electricity in 2030. This reduces emissions by 26 ktCO_2-e at a cost of \$0 per tonne, as the substitution of renewable electricity for NSW grid electricity is unlikely to cost more.

4. Measures to achieve the 2030 targets

4.1. Summary of modelled measures

The selection of the measures for detailed analysis was informed by discussions with the ACT Government. The outcome of these discussions is summarised in the next table.

Table 1: Emissions reduction measures modelled

Intervention		Modelled measure	Comments
Replacement of natural gas for heating	Accelerated replacement of gas space heaters	Replacement with electric room heater five years before end of life	Replacement of gas in heating is consistent with national and international technology trends, and can be readily driven by existing policy instruments. Measures related to the electrification of heating can be promoted through the ACT's Energy Efficiency Improvement Scheme.
		Replacement with electric ducted heater five years before end of life	
	Replacement of gas water heaters	Upgrade to solar hot water systems	
		Upgrade to heat pump storage systems	
Improvements to building energy efficiency	Deep retrofit of housing stock	Retrofits to the building shell of existing houses, spanning installation of ceiling and wall insulation, and installation of double glazing.	These actions are already included in several state-based energy efficiency schemes. However, except for some simple options such as clip-on double glazing and roof space insulation, deep retrofits are complex and costly.
	Higher building code standard for efficiency/ thermal performance	Energy efficiency standards for residential and commercial buildings that are consistent with benefit-cost ratio of 1.	Demanding a higher thermal performance from new residential building can affect housing affordability. It is important therefore to strike the balance between demanding better performance and managing the cost impacts.
Increase uptake of EVs	Provide public access to EV charging stations	Install public EV charging stations at a ratio found in fastest-growing EV markets (1 charging station per 15 vehicles)	The economics of EVs are projected to change rapidly in the next 10 years, to the point that EVs will become cheaper than conventional vehicles in the mid-2020s. However, addressing 'range anxiety' is critical to facilitating consumers' switch to EVs.
	Use EVs in ACT	Replace ACT government fleet cars with EVs	The number of light vehicles in the ACT

	government fleet		government fleet is small, but converting them to EVs will demonstrate leadership. Early conversion can also promote the development of charging infrastructure and broader EV uptake
	Electrification of ACT bus fleet	Replace ACT buses with electric buses	The capital cost of an electric bus compared to a diesel bus is projected to reach parity within the next 10 years. However, providing appropriate charging infrastructure can add substantial extra costs.
Increase uptake of public transport	Increased bus and light rail use	Strengthen Transport for Canberra policy (public transport measures) to achieve projected mode share shifts away from private vehicle use for 2040 by 2030. This was modelled as a two percentage point increase in public transport use is modelled.	Transport for Canberra is already government policy, and hence included in the reference case. The Transport Report provided a scenario that extended the government's Transport for Canberra policy package to 2050, and the 2040 goals of this scenario were brought forward to 2030 to construct a measure based on a shift to public/active transport beyond BaU.
Reduce solid waste emissions	Composting of residential food and garden organics	Divert food and garden organics from single- and multi-use dwellings from landfill to composting facility.	Cost effective treatment of food organics relies on effective source segregation plus dedicated waste collection.
Reforestation and afforestation	Increase urban forest cover	Increase urban forest by 50 per cent by 2030	This measure has significant co-benefits, including improved air quality, biodiversity enhancement and mitigation of heat island effect – an important component of adaptation to climate change. Bushfire risk needs to be managed.
	Procure additional land for afforestation and reforestation	Pay for reforestation-led abatement at prices modelled by CSIRO	The areas of NSW within 100 km of the ACT provide sufficient opportunities for land based abatement for the ACT to meet the 2030 and 2050

			targets.
Maintain 100 percent renewable electricity supply	High uptake of embedded renewable energy and storage	Included in reference case	Price declines indicate installation of solar PV and batteries will become business as usual from the middle of the next decade.
	Procure renewable electricity to cover potential shortfall in supply	Based on AEMO electricity price projections and Energetics electricity market model	This is likely to have zero to minimal additional cost compared with the alternative option of purchasing electricity from the National Electricity Market: renewable electricity prices are likely to be similar to prices in the NEM as forward prices in the 2030s will be set by lowest cost new entry technologies, which are solar and wind.

4.2. Summary of approach to key metrics

For each measure we have calculated the cost and volume of abatement. Key metrics used are as follows:

Table 2: Common metrics across the range of modelled measures

Energy prices			Energy and emissions			Capital	
	Retail	**Economy**					
Electricity (per MWh)	$250	$107	Natural gas emissions factor	0.052	tCO2-e/GJ	Real discount rate	4 percent
Natural gas (per GJ)	$25.70	$11.00	Petrol emissions factor	0.067	tCO2-e/GJ	ACT bond rate	4 percent
Petrol (per kL)	$1,000		Petrol calorific value	34.2	GJ/kL	General interest rate	3 percent
Diesel (per kL)	$1,200		Petrol emissions factor	2.2914	tCO2-e/kL	Share of capital expenditure that stays within the ACT)	33 percent

4.2.1. Replacement of natural gas for heating

The three largest demands for gas are residential heating, ventilation and air conditioning (HVAC), residential water heating and commercial HVAC. The energy baselines in the Integrated Model suggest that the ACT's natural gas demand for residential HVAC falls by 50 percent from 2016 to 2030 while natural gas for residential hot water rises by around 35 percent. Natural gas for commercial HVAC falls by 25 percent.

Given the contribution of emissions from natural gas used for heating, we have included abatement measures to achieve further reductions from those included in the baseline in the period to 2030. These are summarised in the following table and discussed in more detail below.

Table 3: Measures to replace natural gas for heating with electric alternatives

Measure	Action	Cost of abatement ($/tonne)	Volume of abatement in 2030 ($ktCO_2$-e)
Accelerated replacement of gas space heaters	Replacement with room heater 5 years before end of life	$11.61	11.8
	Replacement with ducted heater 5 years before end of life	$16.61	12.5
Replacement of gas water heaters	Upgrade to solar hot water systems	$41.34	30.1
	Upgrade to heat pump storage systems	$238.66	30.1

Accelerated replacement of gas space heaters

The fall in demand for natural gas for HVAC is due to the BaU electrification of space heating, as householders and business owners opt for reverse cycle air conditioners (RCAC**)** in preference to gas heaters at the end of the life of existing gas heaters. The factors that contribute to this are discussed in the Stationary Energy Report.

We have modelled a measure that provides a modest incentive for householders and business owners to replace an old but still functioning gas space heater with a similar sized RCAC i.e. a ducted gas heater is replaced by ducted electric RCAC and room heater is replaced by a split system RCAC. The level of subsidy would cover the financial impact of bringing forward an expenditure that would otherwise happen in a few years less the value of the fuel savings that happens with the swap from gas to electricity.

The measure does not increase the overall abatement in the period to 2050 as the analysis in the Stationary Energy Report suggests that natural gas for space heating will have disappeared well before 2050. The measure merely brings forward this abatement and does result in a modest reduction in emissions in the period to 2030. The measure appears to be cost effective from both the perspective of the participant (householder) and the ACT. We calculate the unsubsidised payback from the perspective of the resident to be around 2.5 years meaning that the level of incentive to drive uptake will be modest. Additional details of the measure are in Appendix C.

Replacement of gas water heaters

Since the banning of electric resistance water heaters, the market has these characteristics:

> *60% of new Class 1A dwellings and 65% of new Class 1B dwellings use gas water heating, with solar and heat pump accounting for 40% and 25% respectively; small electric resistance accounts for the remaining 10% in Class 1B dwellings. In Class 2 dwellings the shares of new installations are 30% small electric resistance, 10% gas and 10% solar/heat pump; the remaining 50% of dwellings have centralised supply of hot water. For replacements of existing systems at the end of their assumed 18 year average life, like for like replacement occurs for 75% of electric systems in Class 1A dwellings and 90% in Class 1B dwellings. Of the remainder, which change technology, it is assumed that half shift to gas and half to solar/heat pump.*[9]

Instantaneous gas heaters are cheaper than solar hot water and heat pumps. Any move to ban gas heaters in order to force a switch to either heat pumps or solar hot water places additional costs on consumers. Alternatively, policy could provide incentives to upgrade to solar HW heaters and heat pump storage heaters (with perhaps an additional incentive if the heat pump HW heater system includes additional solar panels). We have modelled the cost of the upgrade of gas heaters, assuming half are upgraded to heat pumps and half to solar hot water.

We have modelled a measure that would encourage the end of life replacement of an instantaneous hot water heater with a solar HW heater or heat pump, and find that the measure will deliver up to 30.1 ktCO_2-e of emissions abatement. However, replacement with a heat pump is a relatively costly measure. It is worth noting that in this measure the activity is a retrofit, and installations of solar HW heaters and heat pumps in new builds may be lower cost.

The potential for roof space to be more effectively used for solar PV panels needs to be factored into any consideration of support for solar hot water. A non-modelled option could be to reintroduce electric resistance water heaters, as these are low cost, and would have no emissions impact in a 100 percent renewable electricity system, although they are less energy efficient.

4.2.2. Improving building energy efficiency

Two measures that reduce the emissions from the built environment through improvements to the thermal performance of houses were considered. One looks at retrofits to existing houses and the other considers the value of more stringent building codes which would apply to new commercial and residential buildings.

Table 4: Measures to improve building energy efficiency

Measure	Action	Cost of abatement ($/tonne)	Volume of abatement in 2030 (ktCO_2-e)
Improvements to building energy efficiency	Retrofits to the building shell of existing houses	$1,564.31	37.0
	More stringent building shell requirements for new residential buildings	$0.00	5.4
	More stringent building shell	$0.00	12.0

[9] Source: Stationary Energy Report

	requirements for new commercial buildings		

Retrofits to existing houses

We based this analysis on measures identified for the modelling of several state-based energy efficiency schemes. The measures span installation of ceiling and wall insulation, and installation of double glazing. Together, these will result in an HVAC energy saving of around 65 percent at a total cost of $37,000 per dwelling. Key parameters are in the table below, and results summarised in the table above. More details of the measure are in Appendix C.

Key parameters of modelling of deep retrofits

Insulation - Ceiling / envelope	42.6%	$2,200 installed cost
Insulation - Wall / envelope	12.3%	$5,684 installed cost
Insulation - double glazing	11.8%	$9,779 installed cost
Assumed saving	67%	
Electricity saving	1.7	MWh/year
Natural gas saving	5.4	GJ/year
Participant net cost	$17,663	
Lifespan	20	years
Participant net energy cost saving	$557.66	per year
Payback	32	years
NPV of measure	($8,708.72)	
Lifetime abatement	5.6	tonnes CO2-e

While a deep retrofit achieves major gains in energy efficiency, these come at a substantial cost, which presents a barrier to implementation of measures to drive more deep retrofits. Currently retrofits are incentivised through state-based schemes, but receive little uptake because of the high cost of the measure. In certain circumstances deep retrofits could achieve major co-benefits, for example, if they are targeted at lowest-performing housing stock or households facing energy hardship.

More stringent requirements on new houses

The Stationary Energy Report suggested that a requirement for new houses to achieve nine NatHERS stars should be considered.

Quantitative data to support the estimation of the cost effectiveness of this measure suggests that it remains costly in the absence of high industry learning rates. Studies in 2009 and 2010 by, respectively, the Australian Building Codes Board and Master Builders Australia[10] found that upgrades would at best be economically marginal, and in many cases resulted in a negative

[10] "Energy-efficiency: building code star-ratings. What's optimal, what's not", Centre for International Economics, July 2010

economic outcome. More recent work reported by McKinsey & Company[11] suggests that 20 to 40 percent reductions in energy consumption in houses can be realised through measures that will lead to a 10 percent increase in construction costs. However, these reports do not assume significant declines in building compliance costs driven by industry learning in design, construction and materials.

Recent investigations by pitt & sherry[12] [13] and Houston Kemp[14] note the influence of assumed learning rates on modelled costs to achieve high energy efficiency standards but also note the lack of data to support a robust learning rate assumption.

Reflecting these considerations we have modelled more stringent standards in two ways: first, using McKinsey's costs and energy savings to estimate the cost of achieving a nine-star rating; and second, using pitt & sherry's approach to calculate the star rating consistent with a benefit-cost ratio of 1.0 and abatement cost of $0/tonne, assuming a 3 percent learning rate. While this rate is considered extremely conservative by pitt & sherry, we do not believe a higher rate would be robust in a scenario where the ACT is the sole jurisdiction with ambitious building standards.

Details of the two approaches are in Appendix B, and key inputs and results are summarised in the table below.

Approach 1: Calculate costs of achieving nine-star standards		
Additional building cost	$1850 per sqm	10 percent of cost of 200 sqm house
Assumed energy saving	40%	
Participant net energy cost saving	$786.79	per year
Payback	47	years
Lifetime of measure	40	years
ACT net energy cost saving	$337.39	per year
NPV of measure	($18,439.20)	
Lifetime abatement	12.4	tCO2-e
Abatement cost	$1,491	$/tonne
Total abatement in 2030	19.8	ktCO2-e
Approach 2: calculate star rating achievable under BCR of 1.0, abatement cost of $0 and 3% learning rate		
Star rating	6 stars for Class 1, 8 stars for Class 2 buildings	
Abatement cost	$0/tonne	A BCR of 1.0 means the

[11] *https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/building-the-cities-of-the-future-with-green-districts*
[12] *https://www.energy.gov.au/sites/g/files/net3411/f/pathway-2020-increased-stringencyed-new-building-energy-efficiency-final-report-2012.pdf*
[13] *https://www.energy.gov.au/sites/g/files/net3411/f/commercial-building-learning-rates-final-report-2016.pdf*
[14] *http://www.environment.gov.au/system/files/resources/43876dac-f5f8-4ce8-b7f0-c81b2744c080/files/houstonkemp-residential-buildings-regulatory-impact-statement-methodology.pdf*

		abatement cost is zero i.e. the NPV is zero
Natural gas saving	126.1 TJ/year	Assumes the savings is spread equally across electricity and natural gas
Total abatement in 2030	6.6	$ktCO_2$-e

It is notable that in Approach 1, the payback period (the period over which the benefits of the measure equal the costs) is 47 years, longer than the assumed lifetime of the building (40 years). This is based on the avoided costs of energy. Even if additional benefits, such as impact on peak electricity demand costs, and health or comfort improvements, were calculated and included, it is highly unlikely that they would be of a quantum such that the payback period would be less than 20 years. An implication of these contrasting results is that it appears that nine-star efficiency standards are not cost-effective for the ACT under conservative learning rates. However, if more evidence emerges that learning rates are or can be stronger, more ambitious standards may be justified.

More stringent requirements on new commercial buildings

The volume and cost of abatement delivered by more stringent requirements on new commercial buildings was derived from results reported by pitt & sherry[15]. This work showed that 38% reduction in the emissions from commercial buildings in Canberra has a benefit to cost ratio of 1.0. A learning rate of 3% was assumed and no carbon price applied.

The benefit to cost ratio of 1.0 means that the net cost of implementation is zero i.e. the marginal abatement cost is \$0/tCO_2-e. The volume of abatement was derived using the 38% reduction in energy use modelled by pitt & sherry. In the absence of any better data, we assumed that the percentage of 2030 buildings that were subject to the more stringent requirements was 33%, the same as the percentage of residential buildings.

4.2.3. Increase the uptake of electric vehicles

Measures modelled are summarised in the table below. Other options to reduce the costs of EV ownership or provide travel benefits are briefly discussed.

Table 5: Measures to increase uptake of electric vehicles

Measure	Action	Cost of abatement (\$/tonne)	Volume of abatement in 2030 ($ktCO_2$-e)
Increase uptake of electric vehicles (EVs)	Public provision of EV charging stations	\$69.00	27.5
	Use EVs in ACT government fleet	\$1548.00 (2020) to -\$470.00	1.6

[15] *https://www.environment.gov.au/system/files/resources/d5bc9c99-bfa8-4880-aec2-7f31a526d0a9/files/pathway-2020-increased-stringency-new-building-energy-efficiency-standards-2016-update.pdf*

		(2025)	
	Electrification of ACT bus fleet	-$81.25	34.7

Driving a switch from petrol- and diesel-fuelled vehicles to vehicles run on zero emissions electricity is critical to the deep decarbonisation of the ACT economy. This switch is also one of the most promising avenues for strategic intervention by the ACT Government, for several reasons:

- While we find that the amount of abatement from private EVs uptake in 2030s is not large (27 ktCO_2-e), it reflects change of a significant share of the ACT vehicle stock: from EVs constituting less than 1 percent of ACT vehicles currently to 15 percent by 2030. The share of EVs can be expected to grow much further in the 2030s, enabling rapid reductions in transport emissions through that decade.
- Globally, electrified alternatives to internal combustion engine (ICE) vehicles are expected to approach cost competitiveness within the next decade[16] [17], suggesting that the switch does not have to impose significant consumer or economic costs
- EV emissions reflect the emissions intensity of their electricity supply. The emissions of operating an EV fuelled by 100 percent renewable energy are effectively zero, representing a major reduction in emissions compared with ICE vehicles, which emit roughly 200 g CO_2-e per kilometre driven. To maximise the abatement benefits of EV uptake, the ACT government needs to consider the source of the electricity they will use.
- The infrastructure needs and implications of EVs are significantly different from those of ICE vehicles, suggesting that government intervention can smooth what could otherwise be a challenging transition. EVs rely on access to the electricity grid rather than to a supply of imported liquid fuels; as both a very large source of electricity demand and of distributed storage they can impose costs and provide benefits to the electricity system.
- While it is widely expected that nearly all vehicles will be EVs eventually, the speed of this transformation is highly uncertain. Consumer appetite for EVs is not affected solely by cost competitiveness.[18] Policies that have contributed to EV uptake overseas have focused on providing information about their benefits; providing other driving benefits such as access to congestion lanes; and reducing “range anxiety” by providing a network of EV charging stations.[19]
- Government policy will be essential to the management of lifecycle environmental impacts and emissions of EVs. The manufacturing and disposal of EV components, particularly batteries, currently add significantly to EVs’ environmental and emissions impacts. Australia is unlikely to influence EV manufacturing but national and state governments can facilitate recycling of EV components.

However, there are two reasons for caution in implementing EV support policies. First, the speed with which EV costs are projected to fall suggests that incentives to reduce their costs could be inefficient and eventually become redundant. Secondly, due to the short history of policies that support EVs, there is not a robust evidence base that allows the impact of individual policies to be quantified with a high degree of confidence.

[16] ***https://about.bnef.com/electric-vehicle-outlook/***
[17] ***http://www.theicct.org/sites/default/files/publications/EV%20Evolving%20Incentives_white-paper_ICCT_nov2016.pdf***
[18] ***https://energy.gov/sites/prod/files/2017/01/f34/Plug-In%20Electric%20Vehicle%20Policy%20Effectiveness%20Literature%20Review.pdf***
[19] ***https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf***

In Appendix B we present some data that supports our analysis of the measures to support EV uptake. However, there are two key challenges in understanding the broader costs and benefits of these measures in encouraging EV uptake:

- While there is robust evidence that the higher upfront costs of EVs are a barrier to their widespread uptake, there is not robust research on the size of the consumer appetite for switching to an EV once they are cost competitive, *in the absence of other policy measures.*
- Range anxiety reflects both actual and perceived risks associated with battery limits. Technical solutions to address range anxiety may not completely address the perception of the risk.
- Because EV costs are projected to reach equivalence with ICE vehicles in the mid-2020s, policies to address financial barriers become redundant around this point if their intent is to achieve cost-competitiveness.

Private electric vehicles

Providing access to charging

An important influence on EV uptake is the degree of access to charging infrastructure. This relationship is discussed in more detail in Appendix B. ACT residents have significant access to private off-street parking where EVs could be charged overnight. In this the ACT bears more resemblance to US cities or states than those in Europe. US regions where EVs ownership is growing fast feature significant availability of home charging, and also, as in some Californian cities, workplace charging. However, the high ratios of EVs to chargers in Californian cities are unlikely to reflect solely the availability of home and workplace charging. California, like other jurisdictions where EV uptake is increasing rapidly, has multiple EV support policies, including the state Zero-Emission Vehicle program, consumer rebates, access to carpool lanes, progressive electric utility policies, greater model availability and marketing, and continued growth of local electric vehicle promotions across state and city government, and by utilities.[20]

For this modelling we have selected a ratio of 15 EVs per public charger, as a mid-range estimate. It is plausible that other characteristics of the emerging Australian and ACT EV markets could make this ratio lower or higher (for example, federal fuel efficiency standards could increase EV model provision and uptake).

The ACT's reference case for transport is based on the 'Transport for Canberra' scenario in the Transport Report. We calculate that this scenario includes business-as-usual uptake by 2030 of approximately 74,000 EVs or roughly 10 percent of the ACT's forecast passenger vehicle stock.[21] This is a significant increase from the current share of approximately 0.1 percent of the Australian market. However, given the sharp increase in EV cost-competitiveness in the 2020s it is plausible.

Under these assumptions we find that the abatement cost of investing in a public charging network is \$69/tCO_2-e. Potentially, sufficient chargers could be built to incentivise the entire ACT passenger fleet to switch; however we do not believe it is plausible for a single policy to drive that level of change, and so we suggest that a reasonably conservative estimate of the amount of switching by 2030 is that EV uptake is 50 per cent more than that of the baseline scenario, resulting in about 15 percent of passenger vehicles being EVs. This would provide abatement of 27 ktCO_2-e in 2030.

[20] ***http://www.theicct.org/sites/default/files/publications/US%20Cities%20EV%20mkt%20growth_ICCT_white-paper_vF_October2016.pdf***

[21] There is some variation between our calculations and the Transport Report because we assume a minimal role for PHEVs.

Other policies to support private EVs

Providing free parking to EV drivers would result in a significant reduction in the total cost of owning an EV. Based on parking fee forecasts provided by the ACT Government we found that the annual subsidy per EV would average $4144 in 2021. This is based on the average of city and town centre parking fees, and more than covers the additional cost of purchase of a medium-sized EV compared with an equivalent ICE vehicle ($3716).[22] However, with annual emissions reductions per EV estimated at 2 tCO_2-e, this becomes a very expensive abatement policy for the ACT government, with a cost per tCO_2-e of $2,180, paid via foregone parking revenue.

Another policy used in other jurisdictions is allowing EVs to use transit lanes. At early stages of EV market development this may offer a significant benefit in terms of reduced travel time, though this will apply to some consumers and not others. As EV use grows this policy may reduce the utility of the transit lanes.

The higher cost of purchasing an EV is a barrier that is likely to disappear in the 2020s irrespective of ACT government action. Provision of charging infrastructure could plausibly be done by the private sector. However, if the ACT Government wants not only to remove barriers but actively drive a faster and deeper switch to EVs, a strategy that puts at its centre the provision of a well-placed network of public charging stations combined with supporting policies to actively encourage EV uptake appears to be the most effective approach.

Switch to EVs in ACT Government vehicle fleet

Switching as much as possible of the ACT Government fleet to EVs has a minimal impact on emissions – we find that doing so would save 1.6 $ktCO_2$-e in 2030. But it has a number of indirect benefits in terms of demonstrating and promoting an emerging technology, demonstrating commitment to emission reduction actions, and displaying leadership.

Because EV costs fall through the 2020s (see Appendices B and C for details of our calculations on EV costs), the cost of switching the government fleet to EVs depends very much on when this takes place. By the mid-2020s, we find that the cost of switching, and the cost of abatement by doing so, have become negative, but by this stage the ACT government may have lost an opportunity to demonstrate leadership.

Key parameters of EV take-up in the ACT Government fleet	
Total ACT Government vehicles suitable for switching to EVs	683
Total potential annual abatement	1639 tonnes
Total cost of switching fleet (if done in 2020)	$2.5milllion
Total cost of switching fleet (if done in 2025)	-$0.77million
Cost per tonne - 2020	$1,548
Cost per tonne - 2025	-$470

Electrification of ACT bus fleet

The ACT bus fleet currently comprises 432 buses, and will expand by an additional 80 buses. The vast majority of buses run on diesel; buses running on compressed natural gas (CNG) are being phased out. Emissions from ACT buses comprise three percent of ACT transport emissions, or

[22] See Appendix B for details of the costs of EVs relative to ICE vehicles.

just under 34 ktCO_2-e. This suggests that the increased bus use targeted by the ACT to reduce overall transport emissions (which would see public transport use increase from around 8 percent of trips to 16 percent by 2030) will increase emissions from ACT buses in the absence of electrification.

Electric buses will benefit from the same fall in battery costs and increase in performance improvements that drive the improving economics of electric light vehicles. Similar to smaller EVs, electric buses are projected to reach cost parity with diesel buses by 2025[23].

Certain operational aspects make electrification of bus fleets challenging:

- Charging infrastructure – buses can charge overnight at depots, but charging multiple buses at once is a significant draw on the local distribution system. Preliminary government research has found that electrical substations for three of the ACT's four bus depots may need to be upgraded if its fleet were electrified. Alternatively buses can use fast chargers along their routes, but this also requires installation of more expensive charging infrastructure and available space for buses to stop, and management of the impact of charging breaks on bus schedules and costs.
- Charging costs – bus operators will likely have significantly less choice than private vehicle owners as to when vehicles can recharge. This can reduce the ability of bus fleets to exploit time-based differences in electricity prices. On the other hand, as a large electricity consumer, an electric bus fleet operator can potentially negotiate a more competitive electricity supply contract than small customers.
- Range – while most private car journeys are well below the maximum range of most EVs, buses are designed and expected to run as frequently as possible. Larger batteries increase vehicle range, but add weight that reduces the efficiency of the bus.
- EVs maintenance costs less than maintenance of ICE vehicles – because the former requires less maintenance than the latter. As buses are more intensively used than most private vehicles, maintenance costs are a more significant component of total costs of operation.

A meta-analysis[24] of numerous comparisons between diesel and electric buses finds that electric buses' higher upfront and infrastructure costs outweigh their lower maintenance and running costs, to the extent that the total cost of ownership of an electric bus is currently more than 50 percent higher than that of a diesel bus. However, assuming the capital costs of purchasing an electric bus reach parity with diesel by 2025, thereafter the costs of an electric bus could be 50 percent *less.*

This does not automatically mean that by 2025 it will be cost effective to switch all ACT buses to electricity. Electrifying the ACT bus network faces an additional hurdle that the electricity distribution systems feeding the bus depots do not have enough capacity to charge.

We calculate the abatement costs of this measure based on the replacement at end of life from 2025 of ACT diesel buses with electric buses, assuming that from this point on the capital costs of the buses are at parity. We assume that by 2030 all remaining buses are replaced, bringing forward the spending that would occur in later years. We also assume that three bus depots in the territory will need substantial substation upgrades to provide the distribution capacity required to charge the buses. More details of the calculations of this measure are in Appendix C.

[23] ***https://www.bloomberg.com/news/articles/2017-11-13/man-s-583-000-electric-urban-bus-to-test-cities-spending-plans***

[24] Mahmoud, Et al., 2016, 'Electric Buses: A review of alternative powertrains', Renewable and Sustainable Energy Reviews Volume 62, September 2016, Pages 673-684 ***https://doi.org/10.1016/j.rser.2016.05.019***

Economic benefits of ACT leadership in EV

Under the right conditions there is potential for a first mover advantage in EV uptake through training and research opportunities. ACT already hosts institutions leading research in renewable energy and other related fields, suggesting there is a base of knowledge and expertise conducive to clustering benefits. However large-scale training is likely to be subject to national standardisation and open to interstate competition. Other opportunities in manufacturing of EVs and associated componentry are unlikely.

4.2.4. Increase uptake of public transport

The ACT Government's 'Transport for Canberra' strategy contains multiple measures to encourage greater use of public transport (e.g. buses) and active transport (walking, cycling). The emission reduction impacts of a scenario whereby Transport for Canberra measures are extended to 2050 are outlined in the Transport Report and included within the reference case emissions for the ACT.

Due to data challenges we have modelled a simplified strengthening of the Transport for Canberra scenario such that the mode share shift from private car use between 2030 and 2040 is achieved by 2030. While in the Transport Report the mode shift in this period is one percentage point (of journeys) to public transport and one percentage point to active transport, we have modelled a two percentage point shift to public transport. This is to avoid anomalies in the relationships between data sets.

Table 7: Measures to increase use of public and active transport

Measure	Action	Cost of abatement ($/tonne)	Volume of abatement in 2030 (ktCO_2-e)
Increase uptake of public transport	Achieve a two percentage point increase in public transport use above Transport for Canberra scenario	$86.55	23.4

The abatement achieved through this measure is derived from the Transport Report's estimated abatement for 2040. The additional costs of accelerating the strategy are derived from the costs of achieving the current Transport for Canberra policy. There are two broad categories of costs: public expenditure on transport infrastructure and operations, and consumer costs of associated rises in parking fees. This is estimated to bring forward abatement of 23 ktCO_2-e, at a cost per tonne of $86.55. Key parameters of the measure are below, and more details of the modelling approach are included in Appendix C.

Parameters of public transport measure	
Increase in public transport uptake	2 percentage points (from 16% to 18%)
Abatement associated with increase in public transport use	23.4 ktCO_2-e
Avoided private car journeys to work	5,086,957
Cars off the road	11,059

Cost of additional infrastructure	$52.2 million
Annual operating costs for additional public transport services	$890,000
Annual avoided fuel costs	$10.1 million
Cost of increased commuting time	$8.5 million

4.2.5. Reduce emissions from solid waste.

The measure selected to reduce emissions from solid waste was to compost residential food and garden organic matter, instead of sending it to landfill.

Table 8: Measures to increase use of public and active transport

Measure	Action	Cost of abatement ($/tonne)	Volume of abatement in 2030 (ktCO_2-e)
Reduce emissions from waste	Compost residential food and garden organics	$75.00	7.2

The Integrated Model indicates that abatement from switching residential food and garden organics from landfill to compost totals 7,200 tonnes in 2030. Data on the costs of waste collection and processing was provided by the ACT government to give a cost of abatement of $75.00 per t$CO_2$-e.

4.2.6. Carbon sequestration through land use change

Estimating the value of the costs and benefits associated with land use change is extremely challenging, due to limited data availability. As well as carbon sequestration, afforestation and reforestation can provide other important co-benefits such as improvements in biodiversity, water quality and public amenity. Two measures were assessed, and their costs and volumes of abatement in 2030 are summarised below:

Table 9: Measures to sequester carbon through land use change

Measure	Action	Cost of abatement ($/tonne)	Volume of abatement in 2030 (ktCO_2-e)
Carbon sequestration through land use change	Increase urban canopy cover within ACT	$626.12	12.8
	Increase afforestation and reforestation within 100km of ACT	$25.00	More than sufficient to meet target range

Increasing urban forest cover within ACT

The Land Use Report (within ACT**)** and Integrated Model find that increasing the urban canopy cover within Canberra by 25-100 percent would reduce 2030 emissions by 6-26 ktCO_2-e. Increasing urban forest cover by 50 percent, or by 2000 hectares, would reduce emissions by just under13 ktCO_2-e (12.8 ktCO_2-e).

The costs of urban tree planting and maintenance have been derived from a 2011 report by the ACT Commissioner for Sustainability and the Environment[25], and ACT budget papers. Carbon sequestration over time – which changes over the lifetime of a tree – is taken from the Integrated Model. Key parameters of this measure are below and more detail is provided in Appendix C:

Key parameters of increasing urban forest cover within ACT	
Increase in urban forest (percent)	50
Increase in number of trees	382,793
Cost to plant additional trees	$158 million
Maintenance of additional trees (annual)	$535,000
Energy cost saving resulting from additional trees (annual)	$1.2 million
Total lifetime abatement (ktCO_2-e)	223

There are significant co-benefits associated with increased urban forest: these include improving air and water quality, reducing runoff, and reducing ambient temperatures to decrease the 'urban heat island'. Other benefits include improved amenity and biodiversity. Many of these can also be considered adaptation benefits as they increase the resilience of Canberra and its citizens to impacts of climate change such as more extreme heat (see section 6 below for more detail on adaptation benefits).

A 2005 study of the ACT urban forest estimated the annual values of then-existing urban trees with regard to energy cost savings, pollution reduction, and hydrology to total $15.5 million and total amenity value to be $1.1 billion (in 2005 dollars).[26] As these values were calculated using data from US cities that is nearly 20 years old, and as some of the inputs are not publicly available, we do not feel confident in applying them to ACT's future urban forest, but a more recent estimate of the reduction in energy use associated with urban trees by Moore (2009)[27] was included in our calculations.

Reforestation and afforestation within 100km of ACT

The Land Use Report (outside ACT) indicates that the land area with 100km of the ACT will have sufficient capacity to meet the full 2030 target range, and even the 2050 target. This remains the case even if only a very small percentage of the total land resource is able to be accessed for

[25] Maxine Cooper, 2011. 'Report on the Investigation into the Government's tree management practices and the renewal of Canberra's urban forest', ***http://www.environmentcommissioner.act.gov.au/__data/assets/pdf_file/0007/590938/OCSE_TreeInvestigation_Part1_ReportV5_28February2011.pdf***

[26] Cris Brack and Wendy Merritt, 2005. "Quantifying the asset, economic, environmental and social values of Canberra's urban forest estate: A report to support the consultancy to Canberra Urban Parks and Places (CUPP)", Australian National University, Canberra.

[27] GM Moore, 2009. "Urban trees: worth more than they cost", paper presented at the 10th National Street Tree Symposium 2009. ***https://www.treenet.org/wp-content/uploads/2017/06/2009-urban-trees-worth-more-than-they-cost-dr-greg-moore.pdf***

afforestation and reforestation. Abatement through afforestation and reforestation has an indicative cost of $25/t$CO_2$-e, according to several different analyses[28] [29].

Despite the size and low cost of the opportunity, relying solely or predominantly on land sector abatement to achieve the ACT targets would be risky. As the ACT Climate Change Council has noted, a reliance on land sector offsets is not a perfect offset for emissions from fossil fuels because carbon stored on land is vulnerable to being returned to the atmosphere. However, the Climate Change Council has endorsed increasing land carbon in the ACT in order to recover previous losses of land carbon in the territory.[30]

Nonetheless, accessing land sector abatement to 'top up' other emission reduction actions would increase confidence in the ACT Government's ability to achieve the more ambitious 2030 target at low cost, and offer a back-up option in case other measures prove difficult to implement. With land sector abatement still an emerging industry in Australia, driving high quality afforestation and reforestation activities around the ACT is another area where the ACT government can provide leadership.

5. Private and economy-wide mitigation costs

In the previous section we considered the costs and benefits of the different emission reduction measures to develop the net direct costs of different abatement options. In this section we calculate the net economy-wide costs of the mitigation options identified.

The indirect impacts of different market interventions can vary widely, depending on parameters including whether the intervention falls on households or business, the potential industry sectors directly affected, the import component of any spending that takes place, and whether the intervention has the potential to impact (for example) the underlying productivity of capital.

Translation from the direct costs of each abatement option to the economy wide costs is a task ideally suited to application of a Computable General Equilibrium (CGE) model, in this instance the CEGEM model which is tailored to separately identify the ACT economy.

CEGEM is of a genre of economic models that are used extensively by the public sector to assess the economy-wide impacts of major policy changes and economic developments. For example, the Commonwealth Treasury undertook a series of assessments of the economic impacts of climate change response policies using CGE models over the previous decade. The Productivity Commission has also used CGE modelling to consider the impact of economic reforms. An overview of the CEGEM model is presented in Box 2.

Box 2: An overview of the CEGEM model

CEGEM is a multi-commodity, multi-region, dynamic model of the world economy. Like all economic models, CEGEM is based on a range of assumptions, parameters and data that constitute an approximation to the working structure of an economy. Its construction has drawn on the key features of other economic models such as the global economic framework underpinning models such as GTAP and GTEM, with state and regional modelling frameworks such as Monash-

[28] "Modelling and analysis of Australia's abatement opportunities", Energetics, 2016 (Available from ***http://www.environment.gov.au/climate-change/publications/modelling-and-analysis-australias-abatement-opportunities***

[29] "Large-scale abatement potential of the Australian land sector", Reputex, June 2017.

[30] ***http://www.environment.act.gov.au/__data/assets/pdf_file/0004/1135876/20171019-Letter-from-ACT-Climate-Change-Council-to-Minister-Rattenbury-interim-targets.pdf***

MMRF and TERM.

Labour, capital, land and a natural resource comprise the four factors of production. On a year-by-year basis, capital and labour are mobile between sectors, while land is mobile across agriculture. The natural resource is specific to mining and is not mobile. A representative household in each region owns all factors of production. This representative household receives all factor payments, tax revenue and interregional transfers. The household also determines the allocation of income between household consumption, government consumption and savings.

Capital in each region of the model accumulates by investment less depreciation in each period. Capital is mobile internationally in CEGEM where global investment equals global savings. Global savings are made available to invest across regions. Rates of return can differ to reflect region specific differences in risk premiums.

The model assumes labour markets operate in a model where employment and wages adjust in each year so that, for example, in the case of an increase in the demand for labour, the real wage rate increases in proportion to the increase in employment from its base case forecast level.

CEGEM determines regional supplies and demands of commodities through optimising behaviour of agents in perfectly competitive markets using constant returns to scale technologies. Under these assumptions, prices are set to cover costs and firms earn zero pure profits, with all returns paid to primary factors. This implies that changes in output prices are determined by changes in input prices of materials and primary factors.

Figure 5 shows the marginal abatement cost (MAC) curve from a direct perspective using the figures derived previously. As anticipated the abatement costs and potential volumes vary widely, from -$470 per tCO_2-e for use of electric vehicles in the ACT Government fleet in 2025, to $1,564.31 per tCO_2-e for deep retrofitting to buildings. The level of abatement required to achieve a 65 percent reduction is indicated by the broken line at an average cost of $33.23 per tonne, while the 75 percent reduction is unable to be achieved using only the measures identified here.

When considering the economy-wide costs of any policy intervention there are a number of metrics that may be applied. At the national level the most familiar metric to be reported is Gross Domestic Product; at the state and regional levels the equivalent metrics are Gross State Product or Gross Regional Product. Despite the popularity of these metrics they are measures of net economic production and are imperfect as measures of economic welfare.

A superior economic measure is found at the national level in Gross National Income, or the state and regional equivalents of Gross State Income and Gross Regional Income. The changes in these measures are widely used by practitioners as a good approximation to economic welfare. In particular these measures have been used by state and federal governments when analysing the impacts of climate change policies.

Figure 6 shows the economy-wide MAC curve for the abatement options identified above as measured through Gross State Income (GSI). This curve has been developed by application of the CEGEM model described above, and taking into account the economic incidence of each of the policies. Notably, the GSI cost per tonne of abatement lowers to $31.95 per tonne as compared to the direct cost of $33.23 per tonne.

Figure 5: Private costs of identified measures excluding land sector measures

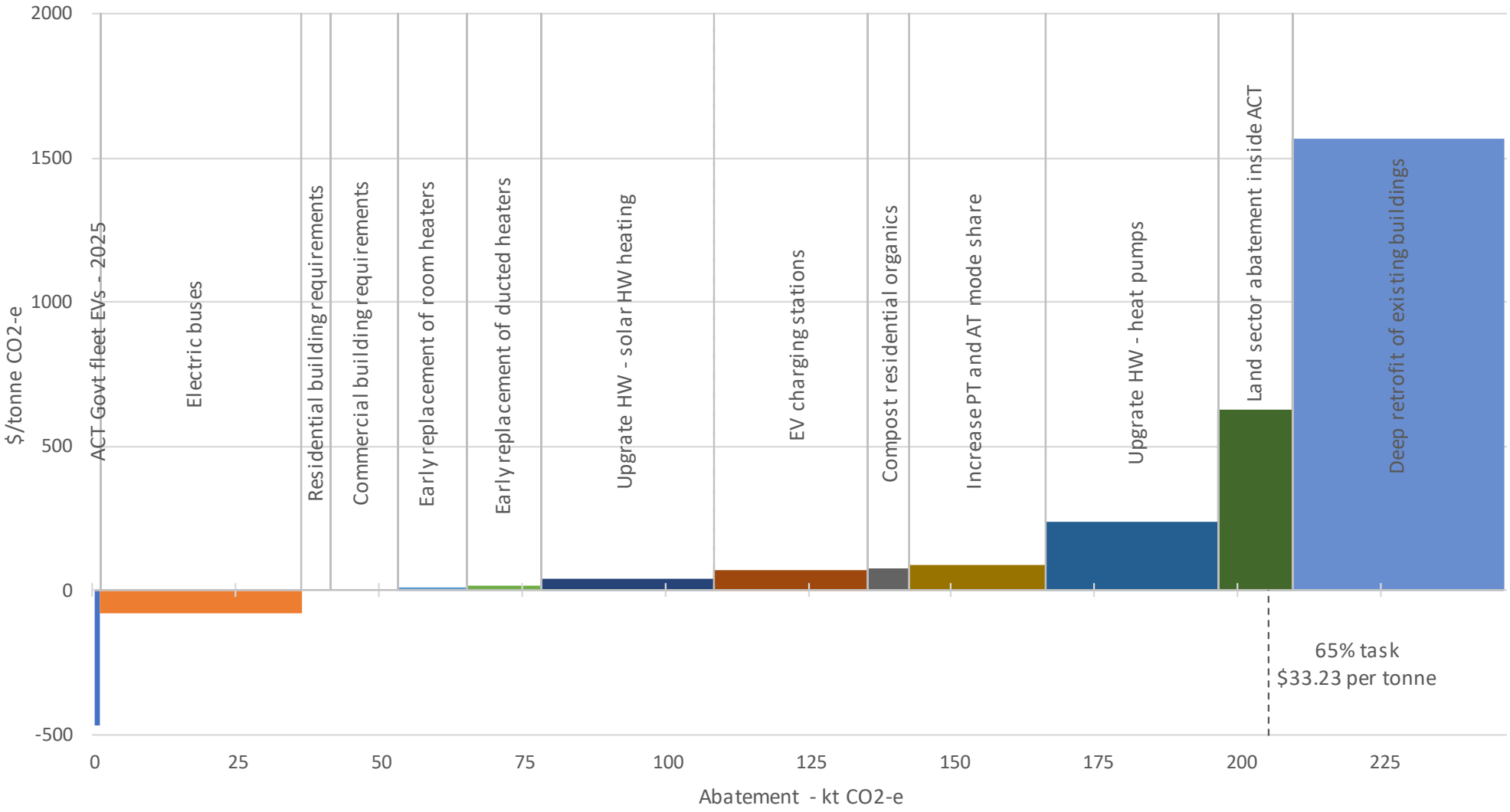
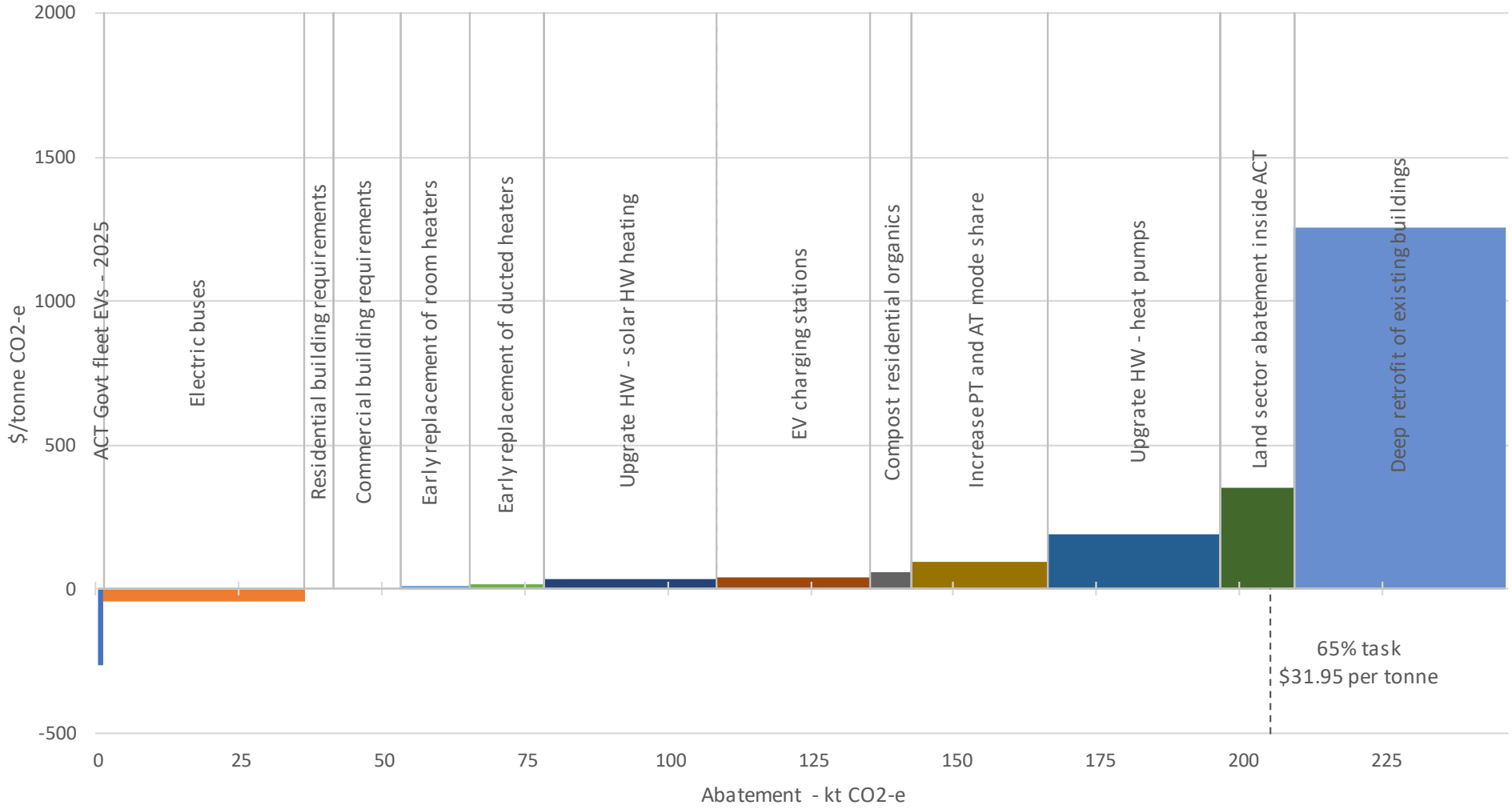


Figure 6. Welfare (GSI) costs of identified measures



As can be seen, while the merit order of the policies remains, the relative costs of each abatement option vary, depending on the economy-wide efficiency of the bases to which they are applied. The shift in the relative costs of the abatement options acts to reduce the average cost per tCO_2-e.

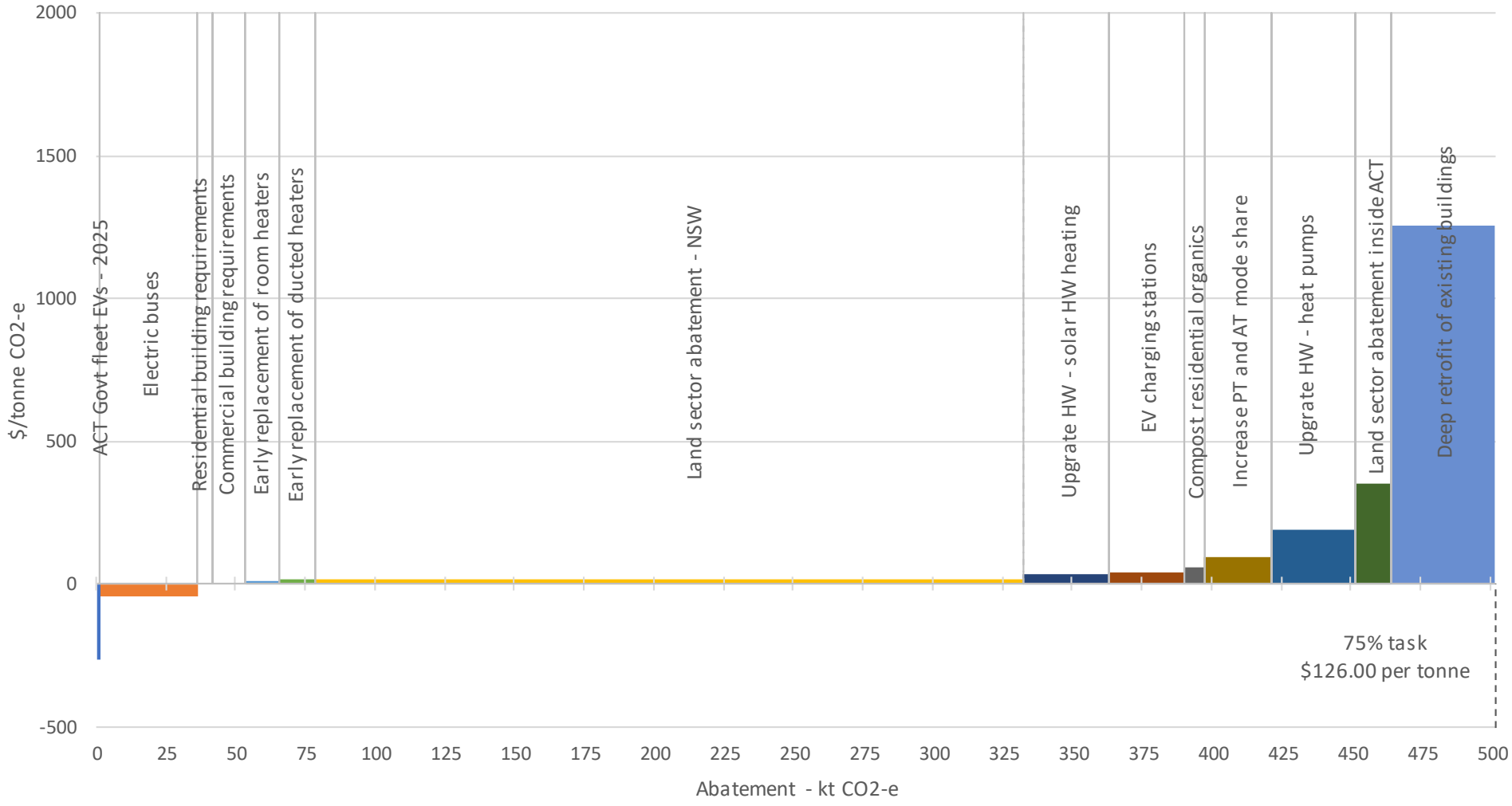
Among the more efficient of the measures (as a ratio of direct to economy-wide costs) are the government purchasing of electric vehicles. With the application of this measure simply reflected through an increased or decreased cost of the government fleet (depending on timing) the efficiency of this measure is broadly a reflection of the efficiency of the revenue base of the ACT government. While the magnitude of the direct net cost or benefit of this measure is relatively high compared to some other options, the underlying reliance on tax revenue reduces this relative to other measures.

As noted above, the measures examined do not provide sufficient abatement to reach a 75 percent emissions reduction target. Figures 7 shows the MAC curves measured both as direct costs and economy-wide costs with the inclusion of enough abatement through afforestation and reforestation measures at a direct cost of $25 per tCO_2-e of abatement to achieve the 75 percent target. The level of the 75 percent target is again indicated with a broken line, including the average abatement cost to that point.

The cost of meeting a 75 percent mitigation target relative to a 65 percent mitigation target is naturally driven by the average cost of the additional measures required. In this instance the cost of mitigation through afforestation and reforestation is in the middle of the range of measures under consideration, so while achieving the 75 percent target encapsulates some of the higher cost measures considered (extending to building retrofits at a direct cost of $1550 per tCO_2-e) the relatively large land sector abatement in New South Wales leads to an average abatement cost of $126.00 per tCO_2-e as compared to $31.95 per tCO_2-e in the 65 percent case.

This significant increase in the average abatement cost is driven in large part by the assumption that we include only enough NSW land sector abatement to meet the 75 percent abatement target while retaining all abatement measures regardless of cost. Relaxation of this constraint at the expense of higher cost ACT based measures has the potential to decrease the welfare cost of mitigation to meet a 75% target to $8.40 per tonne based on purchase of 423 tCO_2-e of NSW land sector abatement

Figure 7. Welfare costs including afforestation and reforestation to achieve 75 percent



6. Adaptation measures, and relationships between measures and benefits

The costs and benefits of the mitigation measures considered in Section 5 of this report take into account the net costs of changes to capital stocks, the imposition of (for example) government fees and charges, changes in productivity in the sectors targeted and changes in energy efficiency for the sectors under consideration. Not considered in this costing was the degree to which climate mitigation measures might have adaptation benefits.

Table 9 outlines the adaptation measures we consider in this report, and Figure 8 shows climate adaptation and co-benefits, along with some of the causal relationships that might be anticipated between mitigation and adaptation measures and the associated benefits.

Table 9: Adaptation measures for the ACT

Objective	Measures
Heat stress prevention	Climate oasis - conversion of nominated locations in each suburb for relief by community during heatwaves
	Decrease urban heat island effect by use of green walls and roofs in town centres/ urban intensification areas
	Cooling town centres with increased use of watered grass, removal of paving, and greater density of summer shade trees
Storm protection	Stormwater capture from side entry pits with subsurface distribution to reduce flash flooding, increase water vegetation, decrease pollutants in waterways
	Stormwater capture and use; permeable pavements; high albedo &/or low thermal mass surfaces

The relationship between climate change mitigation and adaptation is multifaceted. On a global scale, climate mitigation reduces the amount of climate change and therefore the adaptation required to maintain living standards as temperatures rise. On a more local scale, measures to reduce emissions can also contribute to local adaptation to increasing weather extremes. Some adaptation actions have mitigation benefits – such as tree planting to reduce urban heat island effects, which also sequesters carbon. (Conversely, other adaptive behaviours can result in increased emissions, such as increased fossil fuel consumption to provide cooling services.)

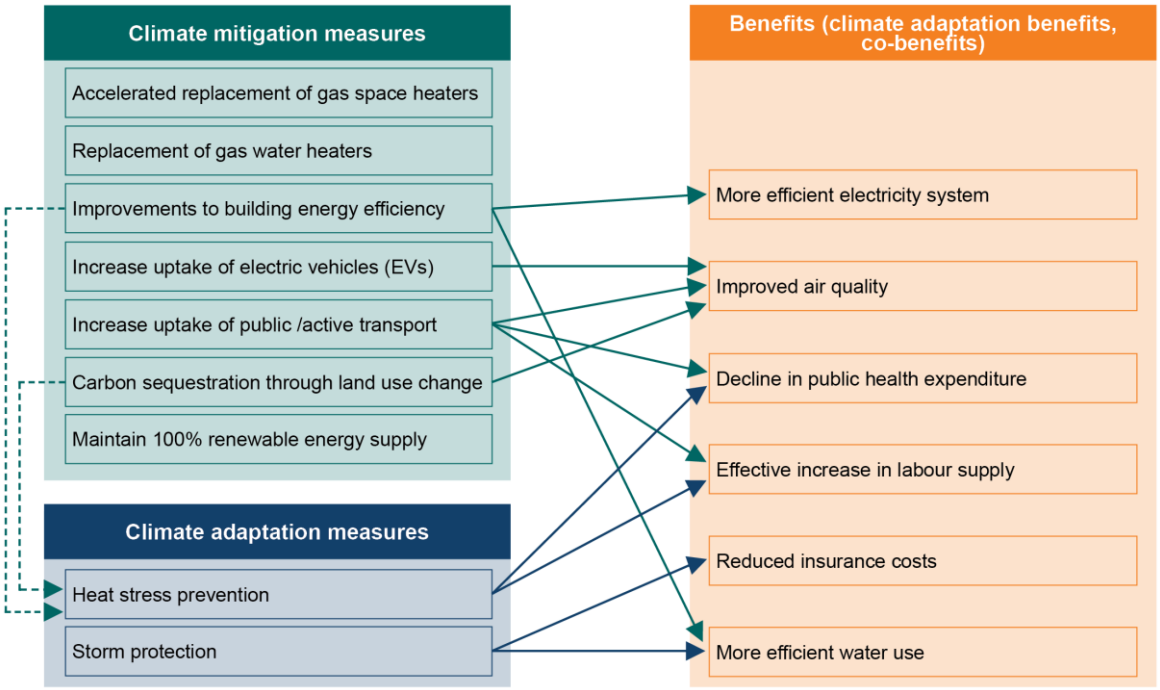
The Intergovernmental Panel on Climate Change defines adaptation as “The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.” A related concept is “adaptive capacity”, which refers to the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. [31]

[31] *https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_Glossary.pdf*

We have defined adaptation benefits as any outcome that increases the capacity of a community to cope with the challenges of climate change. Under this definition, adaptation benefits can include outcomes that are not directly related to the physical impacts of climate change.

A narrower definition of adaptation might require that the purpose of an action is specifically to address the impacts of climate change. Benefits resulting from mitigation measures that happen to improve community capacity and resilience would then be defined as co-benefits. In the discussion below we use the broader definition, in recognition that, irrespective of the motivation for the measure or action, its consequences are to enhance community capacity.

Figure 8: Causal relationships between climate mitigation and adaptation measures and benefits (adaptation, co-benefits)



Potential causal links between individual mitigation and adaptation measures and adaptation benefits are outlined below:

1. **Energy efficiency and electricity systems**: Improving the energy efficiency of buildings improves passive thermal control, reducing peak loads for heating and cooling. Reducing the gap between peak and base demand levels on electricity networks reduces the need for 'gold plating' of infrastructure, improving the productivity of the capital stock in electricity networks.
2. **Energy efficiency and water use**: Improving building energy performance can lead to reduced water use if performance requirements include appliances and equipment, for example dishwashers, washing machines, showerheads.
3. **Energy efficiency and heat stress prevention**: Concern about high energy bills can prevent some energy users from running air conditioning in conditions where it is necessary *for* health and safety. Improving building energy performance reduces the costs of achieving a given level of thermal comfort and thereby the cost of accessing necessary air conditioning.
4. **Electric vehicles and air quality**: Increased uptake of electric vehicles reduces aggregate emission of (for example) NOx, SOx and particulates from the vehicle fleet.
5. **Public/active transport and air quality**: Shifting from the current private transport mix to public and active transport again lowers emissions from the transport fleet, improving air quality.

6. **Public/active transport and public health expenditure**: Switching from cars to active transport improves public health through (for example) improved individual cardio vascular fitness, reducing the load on public health facilities.
7. **Public/active transport and increased labour supply**: Increased levels of physical activity have been shown to improve labour market outcomes, both through increased levels of labour force participation rates and reduced illness.
8. **Carbon sequestration through land use change and improved air quality:** Trees or other biomass planted to sequester carbon also reduces air pollution.
9. **Carbon sequestration through land use change and heat stress prevention**: Trees planted to sequester carbon can also reduce local temperatures through envirotranspiration and shading.
10. **Heat stress prevention and public health expenditure**: Heat stress can be a significant health concern for people in general; even more so for vulnerable individuals such as the elderly and the young. Preventing or reducing levels of head stress can reduce the load on the public health system with subsequent reductions in expenditure.
11. **Heat stress prevention and increased labour supply**: For those individuals in the labour force heat stress can lead to adverse health, with flow on impacts on their ability to engage in the work force.
12. **Storm protection and reduced insurance costs**: If a region is better protected against extreme outcomes such as flash flooding this will be captured by lower insurance premiums.
13. **Storm protection and more efficient water use**: Where stormwater can be captured for use, it can reduce demand for and reliance on other water sources.

Determining the impact of each measure on each benefit requires more detailed information on how the measures are implemented and what responses they produce than was available for this study. This was particularly the case with the ACT's adaptation measures, which are in an early stage of development.

However, as measure become more defined, it should be relatively straightforward to calculate their first-order impacts on resources like electricity and water and therefore on the electricity and water infrastructure systems. It is more complex to calculate health-related impacts like reduced health spending or fewer work days lost to illness, because these effects are often second- or third-order consequences of the measures and can depend significantly on the demographics of the people affected. However, as many of the measures have potential health impacts, and considering the significant economic benefits of improved health (see section 7 below), research and policy development should endeavour to understand and capture potential health improvements.

7. Potential for cost-neutral climate policy

It may be possible to achieve cost neutrality across the full range of ACT climate policies. This is dependent both on the direct cost savings through (for example) improved energy efficiency and through the cost savings that might be achieved through adaptation benefits.

As outlined above, there are a number of mechanisms by which an adaptation benefit can be realised as a consequence of a mitigation measure. An example of the nature of the potential adaptation benefits may be through reduced health budget expenditure resulting from improved temperature control in homes and through reduced insurance premiums as a result of enhanced building requirements.

The links between the cost of mitigation strategies and the extent to which these strategies can drive adaptation benefits are in general not well quantified. With this data limitation in mind it is

illustrative to consider the magnitude of the individual adaptation benefits that would be required for a mitigation package to break even.

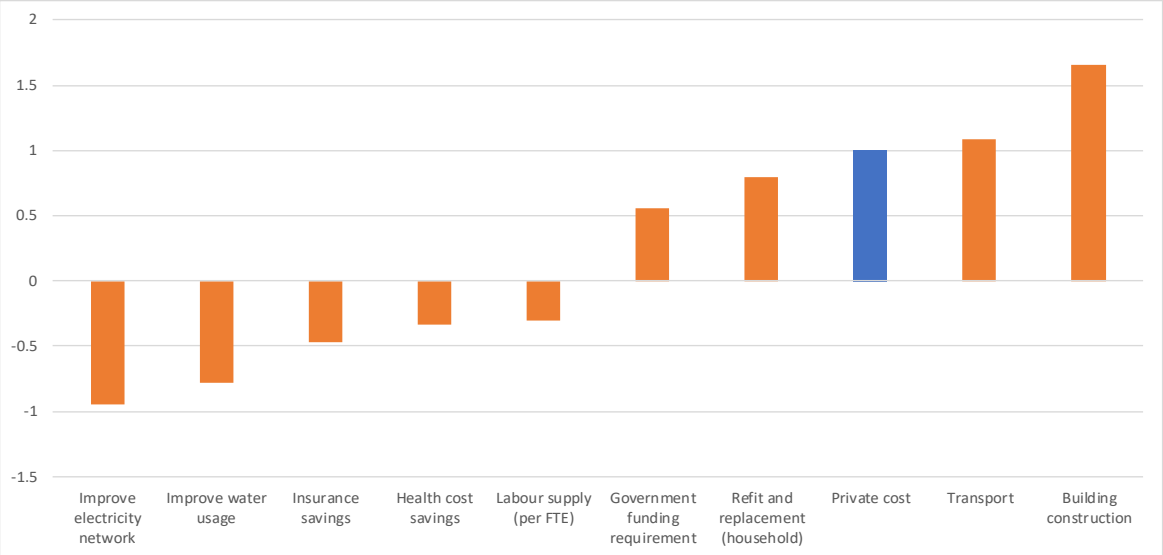
In the absence of available bottom-up or actuarial analysis linking measures with benefits, this break-even analysis can guide qualitative analysis and provide insight as to where future investigation and policy development may be most effective.

In section 5 we found an economic cost of $31.95 per tCO_2-e for the mitigation measures required to reach a 65 percent emissions reduction target, or a total economic cost of $5.8 million. For each individual adaptation benefit to offset the entire mitigation package, we would require in direct terms:

- 19.25 full time equivalent employees to either avoid sickness due to heat related illness or through improved health (active travel)
- Avoid $17.31 million is health expenditure
- Save $12.24 million in insurance costs
- Improve water system productivity by $7.41 million
- Improve productivity of the electricity network by $6.11 million

As is the case for the modelling of mitigation measures the ratio between the economic benefit and the private or direct benefit is a function of the economic incidence. In the case of health expenditure this relates to the efficiency of the aggregate taxation base for the ACT government, requiring a comparatively larger direct health expenditure saving to offset the total mitigation cost than would be required for (for example) improvements in electricity network productivity. These relativities are shown below in Figure 9.

Figure 9. Private costs versus welfare impacts ($ million)



8. Accounting for the social cost of carbon

The ACT Climate Change Council has recommended to the ACT Government that the Social cost of carbon (SCC) be applied in any cost-benefit analyses used to inform public investments or policy and regulatory decisions in the ACT. The SCC represents an estimate of the economic damage caused by each additional tonne of CO_2-e emitted into the atmosphere in a given year. Future costs are discounted to represent what society should be willing to pay in the present.

The SCC recommended by the Climate Change Council is based on the "central estimate" from the United States SCC constructed by the Obama Administration's Interagency Working Group on Social Cost of Greenhouse Gases.[32] The US SCC is derived from three Integrated Assessment Models (IAMs), and comprises four different cost trajectories, reflecting three different discount rates and two cost ranges. The central estimate is based on a 3 percent discount rate and the average cost across the IAMs.[33]

The US SCC accounts for changes in net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs. It does not include other categories of important damages[34], including a number of physical, ecological, and economic impacts of climate change. The omission of these impacts is due to data and research limitations that may be addressed in future. This suggests that current SCC estimates will be revised upwards, as indeed past SCCs have been. However, estimates that are transparently produced and regularly updated help to ensure that policy decisions take account of improving knowledge and evidence.

Including the SCC within cost-benefit analysis of ACT government policy is not straightforward. One inconsistency between recommended Australian approaches to cost-benefit analyses and the SCC methodological framework is the choice of discount rate: 3 percent in the SCC versus 7 percent recommended by the Office of Best Practice Regulation[35].

Another is that the SCC accounts for global carbon costs, in contrast to the direct carbon costs to the ACT of the measures as considered in this analysis. This inconsistency means that the figures presented in Table 10 must be interpreted with significant caution as they do not represent the result of an internally consistent cost benefit analysis.

Subtracting the 2030 SCC of $74[36] from the abatement costs of the measures modelled in this analysis results in a difference less than or close to zero for many of the measures modelled. As noted above, the benefits in this calculation are primarily to the wider world rather than the people of ACT.

Table 10: Private abatement costs after subtracting the social cost of carbon

Measure	Private cost per tonne	Difference to the SCC($/tonne)
Use EV in ACT Government fleet - 2025	-$470	-$544
Electric buses	-$81	-$155
More stringent building requirements (residential)	$0	-$74
More stringent building requirements (commercial)	$0	-$74

[32] Revesz, R. et al., 2017. 'Best cost estimate of greenhouse gases', *Science* 357(6352): 655, referenced in ACT Climate Change Council, Letter to Shane Rattenbury MLA, 19 October 2017.
[33] https://19january2017snapshot.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf
[34] IPCC AR5
[35] PMC OBPR, 2016. 'Cost-benefit analysis", guidance note.
[36] Based on a conversion from 2007 USD to 2016 AUD of the 2030 central estimate of US$50/tCO2.

Early replacement of gas heaters-Room heater	$12	-$62
Early replacement of gas heaters-Ducted heater	$17	-$57
Upgrades to HW heating - solar HW	$41	-$33
EV charging stations	$69	-$5
Compost residential food/garden organics	$75	$1
Increase PT and AT mode share	$87	$13
Upgrades to HW heating - heat Pumps	$239	$165
Land sector abatement inside ACT	$626	$552
Deep retrofits of existing dwellings	$1,564	$1,490

9. Key findings and implications

Key findings of this analysis include:

- Modelling of emissions reduction measures indicate sufficient abatement to meet the 65 percent target at low cost and without requiring tree planting outside ACT
- Modelling suggests the 75 percent target will be significantly more challenging to achieve.
- Abatement costs are important but should not be considered the sole criterion for measure selection. Some measures have low direct abatement costs but significant economic implications, and may therefore face challenges in translation to policy and implementation. For example, more stringent standards for building energy performance could have a number of flow-on impacts, depending on how they are implemented: on the cost of housing construction, which is a major economic driver, or on the location of housing construction, which could leak to neighbouring jurisdictions with lower standards.
- Conversely, some measures have high abatement costs but potentially significant co-benefits and adaptation benefits. Building retrofits, if targeted at particularly poorly performing homes and/or particularly vulnerable households, could produce significant benefits to residents via lower bills, improved comfort, health and heat stress prevention. Similarly, increasing urban canopy cover offers a limited amount of abatement at high cost – but also provides adaptation benefits through cooling, and other important co-benefits in terms of pollution reduction, increased biodiversity and higher amenity values.

It is important to note that the costing of measures is based on currently available information. Many costs are likely to change significantly over time in response to changes in technology, markets, consumer behaviours and business models. Moreover, the modelling we have undertaken cannot capture all the flow-on consequences, both positive and negative.

- We recommend the following priority areas for further research:

- Development of methodologies relevant to the ACT to assess health outcomes associated with specific climate mitigation and adaptation measures, such as investments in active transport and building efficiency

- Development of a robust evidence base on industry learning rates driven by building energy efficiency standards, in order to inform building standards policy development

- Investigation of the impacts of building energy efficiency on electricity system productivity

- We recommend facilitation of electric vehicles uptake as the highest priority area for further policy development and implementation:

  - The potential for electrification of transport to enable deep decarbonisation of the ACT economy is unmatched by emission reduction opportunities in any other sector. While we find that the amount of abatement from private EVs uptake in 2030s is not large (27 kt CO_2-e), it reflects change of a significant share of the ACT vehicle stock: from EVs constituting less than 1 percent of ACT vehicles currently to 15 percent by 2030. The share of EVs can be expected to grow much further in the 2030s, enabling rapid reductions in transport emissions through that decade.

  - While it is widely expected that nearly all vehicles will be EVs eventually, the speed of this transformation is highly uncertain.

  - The expected cost competitiveness of EVs within a decade gives the ACT Government a useful timeframe to develop an EV strategy that includes the measures analysed in this report.

  - As the upfront costs of EVs are likely to reach parity with conventional vehicles in this time, tackling other potential barriers to EV deployment, such as range anxiety and lack of consumer knowledge, will be necessary to maximise voluntary uptake of EVs.
  - Electrification of ACT government vehicles and the bus fleet has benefits beyond direct emission reductions, such as increasing the visibility of EVs in the territory, providing consumer experience of electric vehicles, and providing demand for a charging network and electric vehicle models. A further potential benefit is in contributing to the reputation of the ACT as a hub for electric vehicle research. All of these benefits suggest that the ACT should not wait until EVs are cheaper than conventional vehicles to make the switch, but should weigh the additional benefits accrued by demonstrating leadership against the extra costs of investing in EVs while they still maintain a cost premium.

  - A further benefit of choosing early rather than late investment in EVs is that the ACT will be more likely to be ready to make the switch to EVs if costs fall faster than projected.

- Because the transport sector as a whole is the largest source of ACT emissions in the medium term, a package of measures will be required to decarbonise the whole sector. As the direct and economy-wide impacts of individual transport policies lead to substantial interactions among sub-sectors, we recommend that further development of ACT transport strategy beyond the current 'Transport for Canberra' commitments include the following elements

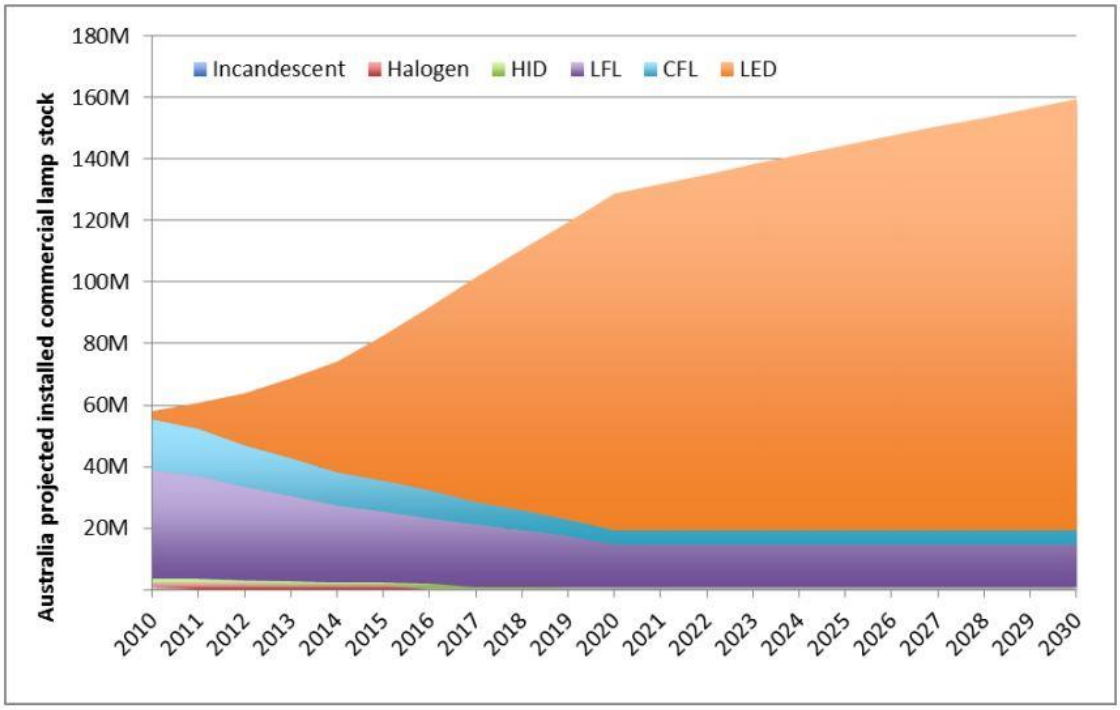
- Research to develop and test models of mode shifting among various types of private, public and active transport resulting from changes to costs and services
- Robust modelling of mode shift impacts in terms of consumer behaviour, financial flows and infrastructure needs
- Development of risk assessments and indicators for further technology-induced disruption to the transport sector via advances in mobility-as-a-service and autonomous vehicles.

Appendix A Trends in lighting in Australia and the case for lower electricity demand

The rapid global reduction in the costs of LED lighting is being experienced in Australia. It has been helped along by policy measures such as the energy efficiency obligation schemes that operate in the ACT, Victoria, New South Wales and South Australia. National analyses project that LEDs will become the dominant form of lighting in Australia by 2030.[37]

The figures, taken from the LED Product Profile below, show how LED lights will come to dominate lighting in both the residential and commercial sectors and how this will drive down the demand for electricity for lighting.

Figure A1: Projected installed commercial lamp stock in Australia 2010-2030 (Figure 29, LED Product Profile)



[37] *http://www.energyrating.gov.au/sites/new.energyrating/files/documents/170815_LED_Product_Profile_Final_0.pdf*

Figure A2: Projected installed residential lamp stock in Australia 2010-2030 (Figure 30, LED Product Profile)

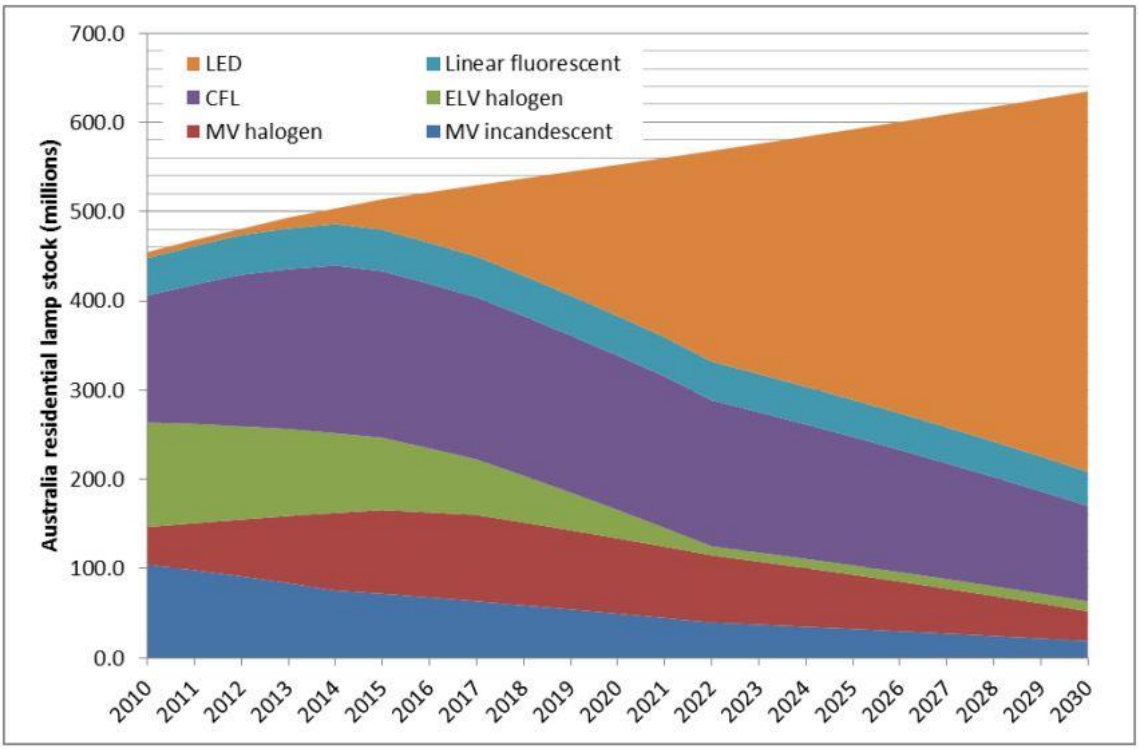


Figure A3: Estimated Australian commercial lighting energy consumption to 2030 (Figure 36, LED Product Profile)

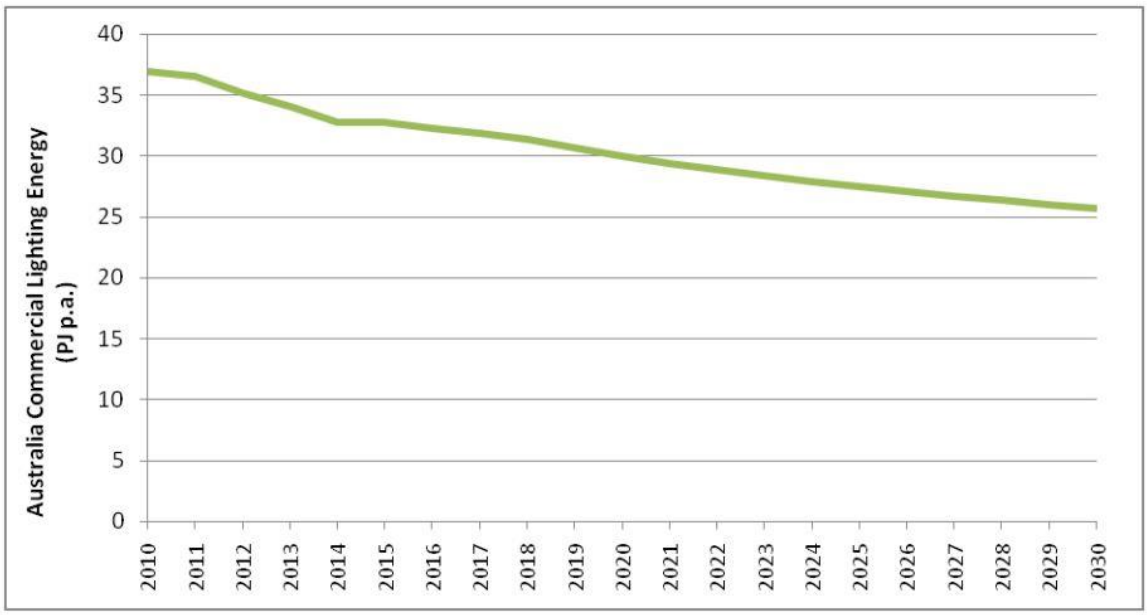
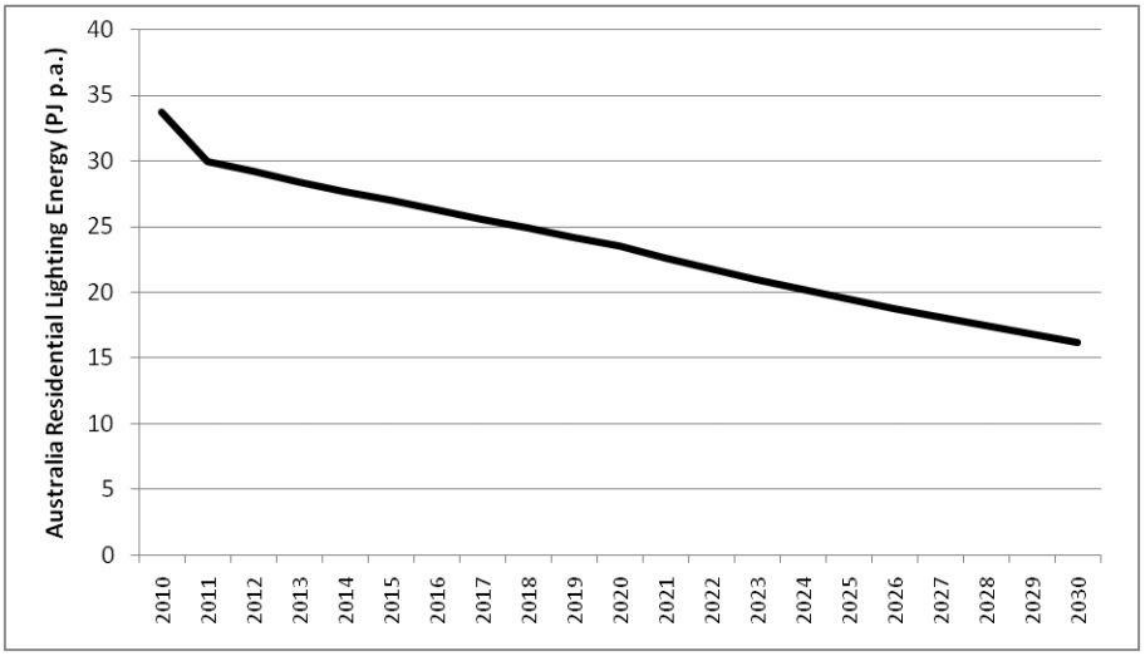


Figure A4: Estimated Australian residential lighting energy consumption to 2030 (Figure 35, LED Product Profile)



Consumer acceptance of LEDs does depend on a number of factors: consumer understanding and valuing of the comparative costs and benefits of LEDs, and consumer confidence in the quality and reliability of the lighting service provided. These considerations need to be addressed to enable a market-wide adoption of this technology.

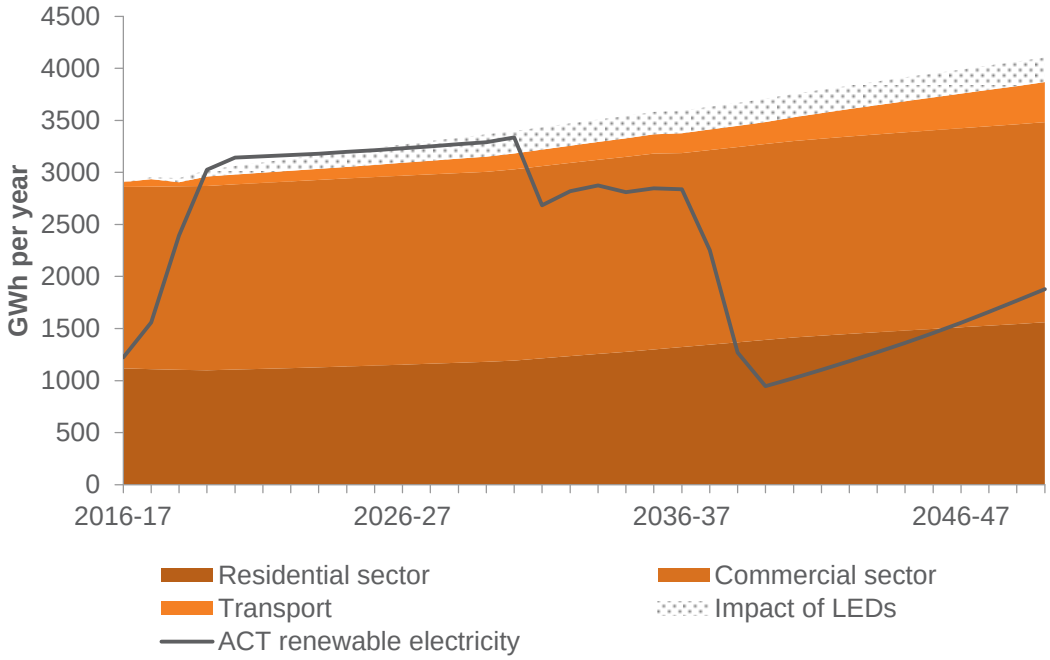
This is likely to be done through national policy. National Minimum Energy Performance Standards (MEPS) for LEDs, and the gradual phase-out of halogen lights, are measures currently under consideration by the federal government. Following several rounds of consultation, the government has developed a 'preferred option', which is to introduce MEPS for LED lamps in March 2019, phase out halogen light bulbs (excluding downlights) in October 2019 and make changes to the Greenhouse and Energy Minimum Standards (GEMS) Act to facilitate MEPS on LED luminaires to allow the phase out of halogen downlights (anticipated by 2021). These measures are estimated to have a net cost of -$187/ tCO_2-e. [38]

ACT will be a beneficiary of these policies. While the emissions reduction value of the switch to LEDs is zero if the electricity supply is 100 percent renewable energy, the LED-induced reduction in electricity demand will help the territory minimise the costs of maintaining a 100 percent renewable energy supply.

Our assessment of the impact of the BaU uptake of LED lighting is shown in Figure A6, which shows how the projected available supply of renewable electricity is more than sufficient to meet demand in this scenario.

[38] Following several rounds of consultation the government is preparing a Decision RIS (DRIS). The DRIS will be submitted to the Council of Australian Governments' (COAG's) Energy Council and the New Zealand Government to decide whether to implement the policy proposals and update and introduce new energy efficiency regulations for lighting products. The DRIS is expected to be considered by Energy Ministers at the end of the year.
http://www.energyrating.gov.au/news/lighting-%E2%80%93-updated-policy-positions

Figure A6: The electricity balance - effect of cost effective LEDs



Appendix B The uptake of EVs

EVs currently face multiple barriers to uptake in Australia. Critical barriers are the existing higher cost of ownership of an EV and access to charging infrastructure. Figure B1 shows that Victorian consumers identify these as the most important targets for current government policy.

Figure B1: Policies to promote the uptake of EVs[39]

In this section, we examine these two key barriers.

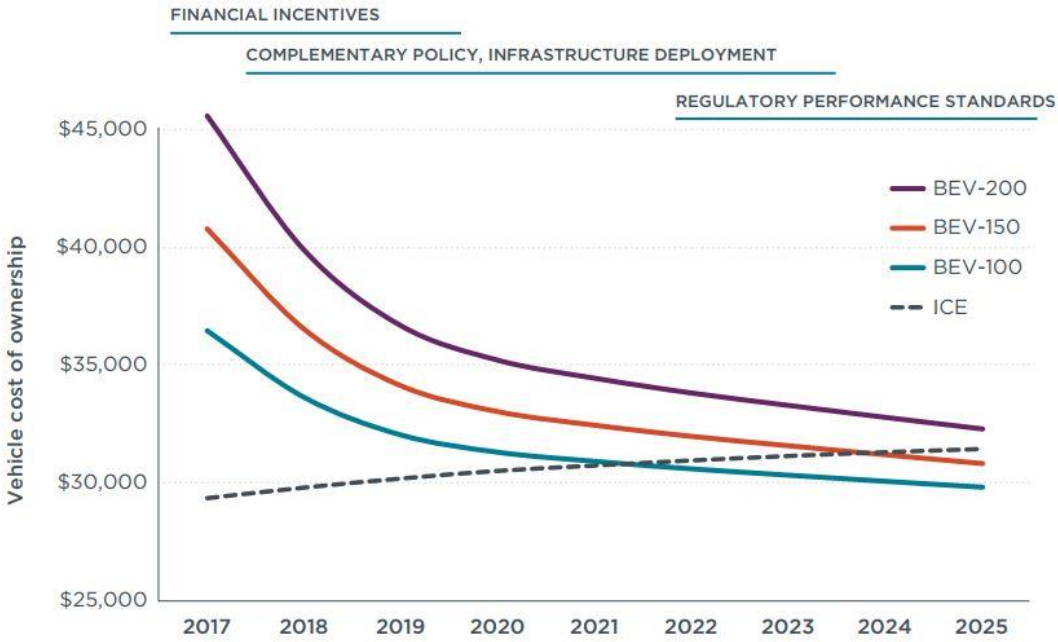
When will EVs be business as usual?

Figure B2 is from an analysis by the International Council for Clean Transportation[40], which compared the first-owner four-year cost of operation for a medium passenger car for seven major electric vehicle markets: Canada, China, Germany, the Netherlands, Norway, the United Kingdom,

[39] Source: "The state of electric vehicles in Australia", ClimateWorks/ARENA, June 2017
[40] ***http://www.theicct.org/sites/default/files/publications/EV%20Evolving%20Incentives_white-paper_ICCT_nov2016.pdf***

and the United States. This analysis finds that the costs of owning and operating an EV becomes competitive with an equivalent ICE vehicle by the mid-2020s, after which point EVs are likely to be cheaper.

Figure B2: Average cost of ownership for battery electric vehicle technology (of 100-, 150- and 200-mile electric range) compared with a conventional internal combustion



Importantly, the *upfront* cost of an EV is also forecast to be less than that of an ICE vehicle by the mid-late 2020s. The forecast of a crossover in competitiveness by (or before) 2025 is shared by other analysts including Bloomberg New Energy Finance[41] and UBS[42]. Together, these forecasts suggest that the total cost of ownership and then the purchase price of EVs will fall below the corresponding figures for ICE vehicles within the next few years, and once this occurs the financial barrier to the uptake of EVs will fall away.

These projections are global or regionally differentiated; no Australia-specific forecast is available. Therefore for this modelling exercise we have applied the projected costs from the ICCT study.

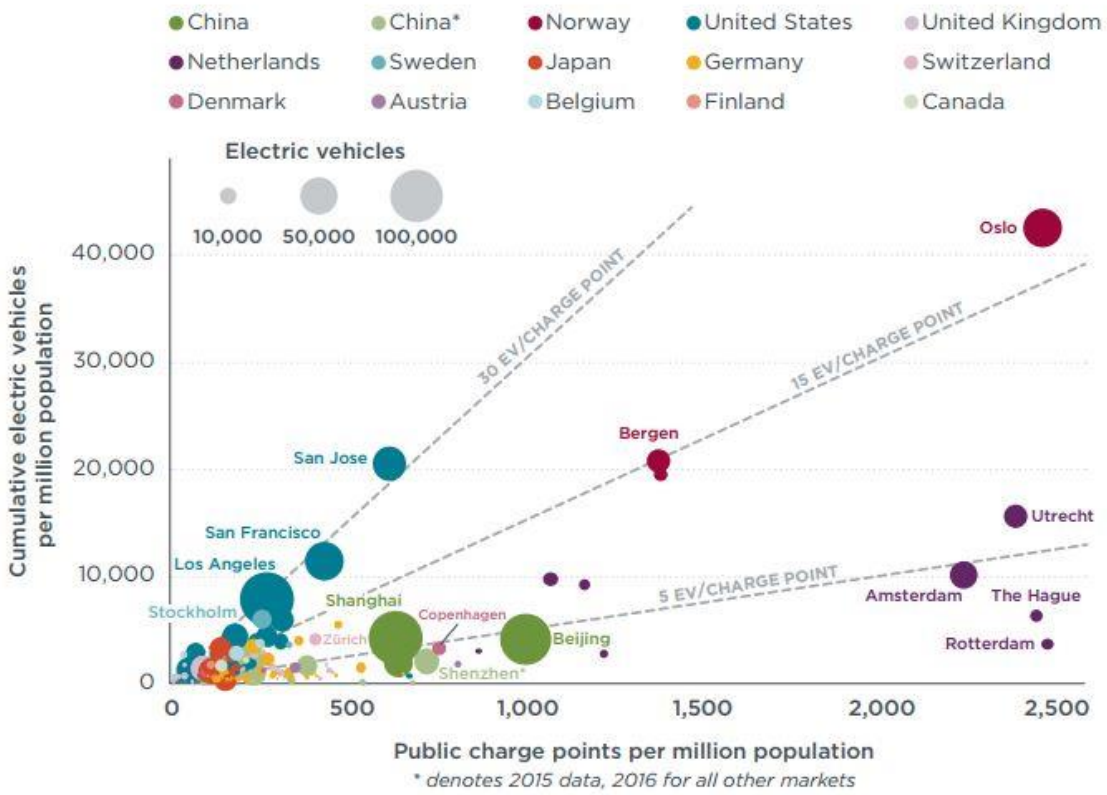
The value of public charging stations

There is solid research underpinning the proposition that increasing the provision of charging stations for EVs helps drive greater EV uptake.[43] [44] A network of charging stations that enables long journeys is widely regarded as a pre-requisite for bulk EV uptake even in markets where most vehicles' daily travel is far less than the maximum charge distance.[45] Quantifying the relationship between charging infrastructure and EVs is much less robust. The study by Hall and Lutsey[44] of high-EV-uptake markets found that public provision of charging stations is much higher in these

[41] *https://about.bnef.com/electric-vehicle-outlook/*
[42] *http://www.advantagelithium.com/_resources/pdf/UBS-Article.pdf*
[43] *https://www.energy.gov/sites/prod/files/2017/01/f34/Plug-In%20Electric%20Vehicle%20Policy%20Effectiveness%20Literature%20Review.pdf*
[44] "Emerging Best Practices for Electric Vehicle Charging Infrastructure", Dale Hall and Nic Lutsey, International Council on Clean Transportation, 2017 (*http://www.theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf*)
[45] *https://energy.gov/sites/prod/files/2017/01/f34/Plug-In%20Electric%20Vehicle%20Policy%20Effectiveness%20Literature%20Review.pdf*

markets than in markets with relatively low EV uptake, but that the ratio of EVs to chargers ranges from less than 5-to-1 to over 30-to1 (See Figure B3, below, from this study.)

Figure B3: Public charging infrastructure and EV registrations per million population by metropolitan area, with size of circles indicating total EVs



A similar range is found across multiple studies[46].

Table B2: Indicated average EV/public charge point ratios (Source: IEA 2017)

Organisation	Region	EV/public charge point ratio	Source
European Council	European Union	10	European Parliament (2014)
NDRC	China	8 (pilot cities), 15 (other cities)	NDRC (2015)
IEA EV Initiative	Worldwide	8 (2015), 15 (2016)	EVI (2016,2017)
EPRI	United States	7-14	Cooper & Schefter (2017); EPRI (2014)
NREL	United States	24	Wood et al. (2017)
CEC/NREL	California	27	CEC & NREL (2017)

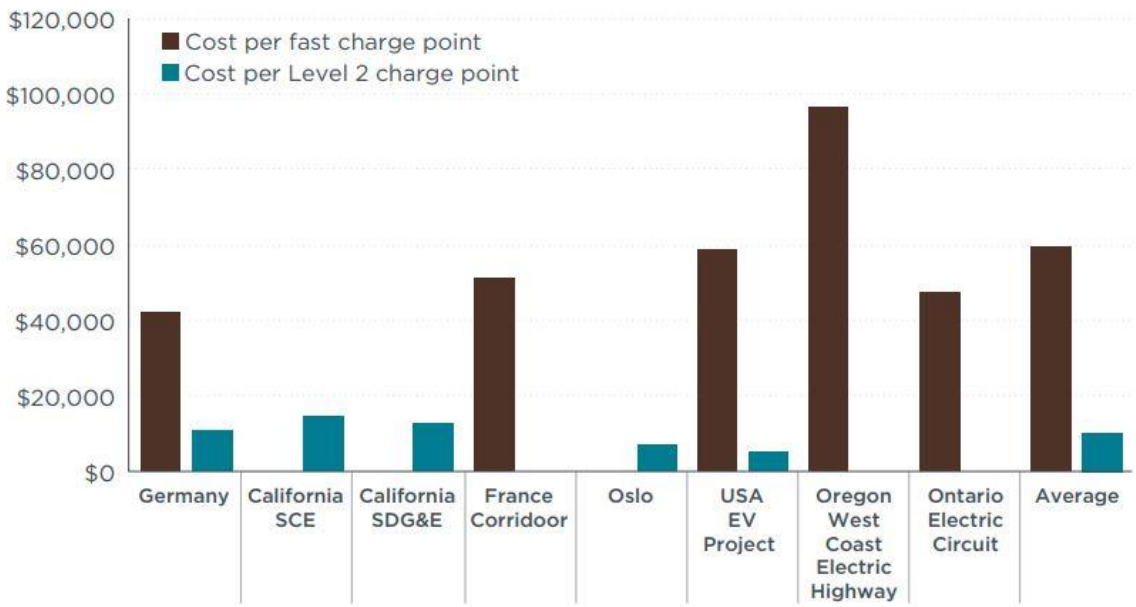
[46] *https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf*

Hall and Lutsey suggest that the difference in ratios may reflect different populations' access to charging at home and at work.

> *"Electric vehicle owners in California more frequently have access to home and workplace charging, and one public charger per 25 to 30 electric vehicles is typical. In the Netherlands, private parking and charging are relatively rare, and one public charger per 2 to 7 electric vehicles is typical... [I]t seems clear that there is no ideal global ratio for the number of electric vehicles per public charge point. Comparisons of similar markets still offer an instructive way to understand where and how charging is insufficient. Lagging electric markets can strive toward the leading benchmarks of comparable cities, while top markets continue to set new benchmarks as the market and its chargin infrastructure coevolve."*[47]

A second question is the type of charging station provided. 'Level 1' charging points provide less than 2kW of power, and so a passenger vehicle needs to be connected to the charger for 8 or more hours to fully charge. These are typical at-home chargers accessed by a standard power point. 'Level 2' charging stations provide power of 3.8-22 kW, charging at a rate of 18-40km/hour. These are significantly cheaper than DC fast charging stations, which operate at 50 kW or above and can recharge a passenger vehicle in under an hour. The costs of charging infrastructure differ significantly across different markets. Figure B4 below shows the cost per charging station of a Level 2 and DC fast charger across seven government charging infrastructure programs, as well as the average costs across all seven programs. For this modelling exercise we use the average costs for each charger, and a ratio of nine level 2 chargers for every one DC fast charger, reflecting the proportion of each in Californian cities.[48]

Figure B4: Approximate program-level costs of Level 2 and DC fast charging stations from selected major government charging infrastructure programs (Source: Hall and Lutsey, 2017)



[47] ***http://www.theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf***
[48] ***http://www.theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf***

Appendix C Details for some measures

ACT Government - Analysis of mitigation actions to 2050:Analysis of measures
Replacement of gas heaters

The measure is the bringing forward of the otherwise BaU end of life replacement of a gas space heater with a RCAC. The implementation cost is the lost interest associated with expenditure occuring earlier than at the end of life.

We will assume that this is a pre-end-of-life replacement, and allow $500 to cover the additional labour associated with installation of the more complex replacement systems.

The NPV for the ACT economy will only consider the purchase price and the labour cost stays in the ACT economy.

Note that some of the figures in this sheet are taken from an associated workbook (Measure-Electrification of Space Heating).

No. of year brought forward	5	years
Total pool of opportunity in 2030	24,321	tonnes CO2-e
Pool of opportunity for Non-ducted System	11,813	tonnes CO2-e
Pool of opportunity for Ducted System	12,508	tonnes CO2-e
ACT per household Gas consumption per year Non-ducted	10,930	MJ/year
ACT per household Gas consumption per year Ducted	40,968	MJ/year
Non-ducted System		
Participant cost	$347	
Lifespan	15	years
Additional electricity	0.53	MWh/year
Participant net energy cost saving	$147	per year
Payback	2.4	year
ACT net energy cost saving	$62.94	per year
ACT net cost	$347	
Present value of savings	$315	
NPV of measure	-$32.7	
Measure's lifetime abatement	2.8	tonnes CO2-e
Abatement cost	$12	$/tonne
Total abatement available for the measure	11.8	kt CO2-e
Ducted System		
Participant cost	$988	
Lifespan	15	years
Additional electricity	2.7	MWh
Participant net energy cost saving	$381.07	per year
Payback	2.6	years
ACT net energy cost saving	$162.47	per year
ACT net cost	$988	
Present value of savings	$812.34	
NPV of measure	($175.32)	
Measure's lifetime abatement	11	tonnes CO2-e
Abatement cost	$17	$/tonne
Total abatement available for the measure	12.5	kt CO2-e

ACT Government - Analysis of mitigation actions to 2050:Analysis of measures
Upgrades to HW heating

The measure is to replace instantaneous gas hot water heaters with heat pumps or solar HW heaters

We will assume that this is an end-of-life replacement, and allow $500 to cover the additional labour associated with installation of the more complex replacement systems. The $500 is added to the participant cost but is not included in the cost to the ACT economy as we assume all this money is circulated in the ACT economy.

The NPV for the ACT economy will only consider the purchase price

Baseline gas used for HW in 2030	1,169	TJ	
Gas consumption per house with gas HW heating	9.9	GJ/year	This is average lifetime gas saving from "EEIS contribution to Cost of Living Impact Statement" divided by the life, and is therefore the amount of gas used and also the amount of gas saved by a conversion to a HW heater that does not use gas.
Total pool of opportunity in 2030	118,035	houses	
Natural gas saving	9.9	GJ/year	
Case for heat pumps			
Participant net cost	$2,700		
Lifespan	15	years	
CoP	4		
Additional electricity	0.6875	MWh	
Participant net energy cost saving	$82.54	per year	
Payback	33	years	
ACT net energy cost saving	$35.16	per year	
ACT net cost	$2,200		
Present value of savings	$374		
NPV of measure	($1,826)		
Lifetime abatement	8	tonnes CO2-e	
Abatement cost	$239	$/tonne	
Total abatement in 2030	30	kt CO2-e	Assumes 50% of dwellings take-up heat pumps
Case for solar HW			
Cost	$3,200		Indicative price in 2017 from supplier websites
Lifespan	15	years	
Additional electricity	0	MWh	
Participant net energy cost saving	$254	per year	
Payback	13	years	
ACT net energy cost saving	$109	per year	
ACT net cost	$2,700		
Present value of savings	$2,384		
NPV of measure	($316)		
Lifetime abatement	8	tonnes CO2-e	
Abatement cost	$41	$/tonne	
Total abatement in 2030	30	kt CO2-e	Assumes 50% of dwellings take-up solar HW

Deep retrofits of existing dwellings

The measure calls for major upgrades to the building shell of an existing dwelling			
The NSW Energy Efficiency model included the following measures. The total energy saving of 67% is close to the target value in the Stationary Energy report (see Table 5).			
We will use $17.7k as the cost to achieve the improvement.			
Activity name	Energy savings % of end use	Installed Cost	
Insulation - Ceiling / envelope	42.6%	$2,200	<- Extracted from the NSW Energy Efficiency model
Insulation - Wall / envelope	12.3%	$5,684	
Insulation - double glazing	11.8%	$9,779	
	66.7%	$17,663	
Average energy savings in a house heated by gas			
Households in 2030	197,000		ABS 32360DO001_20112036 Household and Family Projections, Australia, 2011 to 2036
Electricity used for HVAC in 2030	493	GWh	We use the 2030 figures from the baseline because they capture the BAU changes in performace that will happen.
Gas used for HVAC in 2030	1,588	TJ	
Electricity used for HVAC per household	2.5	MWh	
Gas used for HVAC per household	8.1	GJ	
Assumed saving	67%		
Electricity saving	1.7	MWh/year	
Natural gas saving	5.4	GJ/year	
Participant net cost	$17,663		
Lifespan	20	years	
Participant net energy cost saving	$557.66	per year	
Payback	32	years	
ACT net energy cost saving	$239.11	per year	Assumes energy cost stays constant in real dollar terms
ACT net cost	$11,834		
Present value of savings	$3,125		
NPV of measure	($8,708.72)		
Lifetime abatement	5.6	tonnes CO2-e	
Abatement cost	$1,564.31	$/tonne	
Households in 2020	166,000		Despite using the energy consumption for HVAC in 2030, we use the houseing stock in 2020 to avoid counting new builds.
% of houses in 2020 are demolished	20%		Note: This assumes a 50 year life for houses
Households in 2030 that were built before 2	132,800		Assumes that new building codes apply from 2020
Total abatement in 2030	37.0	kt CO2-e	

ACT Government – Analysis of mitigation actions to 2050: Analysis of measures
More stringent building requirements – Residential buildings

The measure demands more stringent requirements on the building shell of new residential buildings

ALTERNATIVE APPROACH BASED ON REGULATIONS CONSISTENT WITH A BCR OF 1

Assume 3% learning rate and BCR of 1.0 enables achievement of 6-star class 1 and 8-star class 2 residential buildings, based on Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis: 2016 Update for Residential Buildings (https://industry.gov.au/Energy/EnergyEfficiency/Non-residentialBuildings/Documents/Pathway-to-2020-for-Increased-Stringency-in-New-Building-Energy-Efficiency-Standards-2016-Update.pdf). The BCR of 1.0 corresponds to energy savings of 11%.

Abatement cost	$0.00	$/tonne	A BCR of 1.0 means the abatement cost is zero i.e. the NPV is zero
Electricity used by resi sector in 2030	1,249	GWh	
Gas used by the residential sector in 203	2,928	TJ	
Overall saving for a BCR of 1.0	11%		
% of buildings in 2030 that are new	33%		These are the buildings built after 2030 and which are subject to the new codes.
Natural gas saving	105.0	TJ/year	Assumes the split of savings between electricty and gas is proprotional to the split of actual consumption of electricty and gas.
Total abatement in 2030	5.4	kt CO2-e	<- This has included an adjustment to account for the BaU fall in NG used for HVAC.

Our original approach aiming for a 40% reduction

Quantitative data to support the estimation of the cost effectiveness of the measure is difficult to find. In 2009, the Australian Building Codes Board undertook an assessment of a requirement to raise the thermal efficiency of residential buildings to six stars. The ABCB found that the upgrade would at best be economically marginal, and in many cases

More recent work reported by McKinsey&Company (https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/building-the-cities-of-the-future-with-green-districts) suggests that 20 to 40% reductions in energy consumption in houses can be realised through a 10% increase in construction costs. We have based our analysis on building costs of $1850 per m2 (https://www.bmtqs.com.au/construction-cost-table) and a 200 m2 house, a 10% increase in building costs and a 40% reduction in energy use.

Average energy savings in a house heated by gas			
Households in 2030	197,000		ABS 32360DO001_20112036 Household and Family Projections, Australia, 2011 to 2036
Electricity used by households in 2030	1,249	GWh	We use the 2030 figures from the baseline because they capture the BAU changes in performance that will happen. The total energy use for houses is used because we are applying the McKinsey numbers.
Gas used by households in 2030	2,928	TJ	
Electricity used per household	6.3	MWh	
Gas used per household	14.9	GJ	
Assumed saving	40%		Based on McKinsey numbers
Electricity saving	2.5	MWh/year	
Natural gas saving	5.9	GJ/year	
Participant net cost	$37,000.00		<-This is 10% of the $1850 per m2 for a 200 m2 house
Lifespan	40	years	
Participant net energy cost saving	$786.84	per year	
Payback	47	years	
ACT net energy cost saving	$337.41	per year	
ACT net cost	$24,790.00		
Present value of savings	$6,351.24	$38,615.11	
NPV of measure	-$18,438.76		
Lifetime abatement	12	tonnes CO2-e	
Abatement cost	$1,504.85	$/tonne	
Households in 2030	197,000		ABS 32360DO001_20112036 Household and Family Projections, Australia, 2011 to 2036
Households in 2020	166,000		Despite using the energy consumption for HVAC in 2030, we use the housing stock in 2020 to avoid counting new builds.
% of houses in 2020 are demolished	20%		Note: This assumes a 50 year life for houses
New houses built in 2020 to 2030	64,200		
Total abatement in 2030	20	kt CO2-e	

ACT Government - Analysis of mitigation actions to 2050:Analysis of measures
More stringent building requirements - Commercial

The measure demands more stringent requirements on the building shell of new buildings

Quantitative data to support the estimation of the cost effectiveness of the measure is difficult to find. The simple analysis below is based on the 2016 Update of "Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis: Commercial Buildings". This report stated that 38% reduction in the emissions from commercial buildings in Canberra has a benefit to cost ratio of 1.0. A learning rate of 3% was assumed. No carbon price applied. The resultant energy use per m2 was 328 MJ.

Abatement cost	$0	$/tonne	A BCR of 1.0 means the abatement cost is zero i.e. the NPV is zero
Electricity used by the commercial sector in 20	1,971	GWh	
Gas used by the commercial sector in 2030	1,887	TJ	
Overall saving	38%		
% of buildings in 2030 that are new	33%		These are the buildings built after 2030 and which are subject to the new codes. The figure aligns with the figure from the residential sector.
Natural gas saving	234	TJ/year	Assumes the split of savings between electricty and gas is proprotional to the split of actual consumption of electricty and gas.
Total abatement in 2030	12	kt CO2-e	<- This has included an adjustment to account for the BaU fall in NG used for HVAC.

ACT Government - Analysis of mitigation actions to 2050: Analysis of measures
Encourage EV uptake by providing public access charging infrastructure

This measure is based on the relationship between charging infrastructure and EV uptake discussed in Appendix B
Costs of charging infrastructure are taken from Hall and Lutsey, 2017 'Emerging best practices for electric vehicle infrastructure', ICCT
https://www.theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf

Cost of charging station	
Cost of a level 2 charger in ACT	13200
Cost of a DC fast charger in ACT	79000
EVs per charger	15
Blended cost of additional charger (90% level 2, 10% fast charge)	19780
Blended cost of additional charger per EV	1319
Annual cost of blended charger (10-year life)	1978
Annual abatement per EV	
Assuming replacement of petrol with zero emissions electricity	
Emissions of petrol vehicles (kg CO2/km)	0.2
Average distance passenger vehicle (km '000)	9,500.0
Annual emissions petrol vehicle tCO2	1.9
Total pool of abatement opportunity	
Abatement per charger per year	28.5
Total ACT population in 2030	484239
Total ACT passenger vehicles in ACT 2030	289381
Share of passenger vehicles to be replaced by 2030	5%
Total replaced passenger vehicles	14,469
Total annual abatement (t CO2) in 2030	**27,491**
Cost of abatement (annual charger cost/annual abatement of 15 Evs) $/t CO2	69

ACT Government - Analysis of mitigation actions to 2050: Analysis of measures
Electrification of ACT government vehicle fleet

This measure examines the relative costs of switching to electric vehicles in 2020 and 2025

	Unit		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cost of battery technology (BNEF (USD))	$/kWh storage							109					75
Cost of battery technology (ICCT)	$/kWh storage							150-175					
Average cost of EV ownership (ICCT (BEV-150)	USD		$ 33,000	$ 32,500	$ 32,000	$ 31,600	$ 31,200	$ 30,500	$ 30,100	$ 29,800	$ 29,400	$ 29,000	$ 28,600
Projected average cost of ICE ownership (ICT)	USD		$ 30,200	$ 30,500	$ 30,800	$ 31,025	$ 31,250	$ 31,350	$ 31,500	$ 31,500	$ 31,500	$ 31,500	$ 31,500
Conversion from USD to AUD (xe.com)	1.327												
Average cost of EV ownership (ICCT (BEV-150)	AUD		$ 43,791	$ 43,128	$ 42,464	$ 41,933	$ 41,402	$ 40,474	$ 39,943	$ 39,545	$ 39,014	$ 38,483	$ 37,952
Projected average cost of ICE ownership	AUD		$ 40,075	$ 40,474	$ 40,872	$ 41,170	$ 41,469	$ 41,601	$ 41,801	$ 41,801	$ 41,801	$ 41,801	$ 41,801
Difference in cost between EV and ICE ownership			$ 3,716	$ 2,654	$ 1,592	$ 763	$ (66)	$ (1,128)	$ (1,858)	$ (2,256)	$ (2,787)	$ (3,318)	$ (3,848)

Annual abatement per vehicle- based on ACT fleet report - NB these numbers are not the same as av ACT passenger vehicle, because ACT fleet cars are cleaner but travel further

Emissions of ACT passenger vehicle (eg Toyota Corolla)	kg CO2/km	0.16
Average distance passenger vehicle	km '000	15.0
Annual avoided emissions petrol vehicle	t CO2	2.4

Pool of potential abatement

Number of ACT vehicles that could be replaced:		
wagons	207	
hatchbacks	287	
sedans	123	
SUVs	9	
Minivans	48	
Mini MPV	9	
Total vehicles	683	
Total potential annual abatement	tCO2	**1639.2**

Total cost of switching fleet (if done in 2020)	$ 2,537,755
Total cost of switching fleet (if done in 2025)	$ (770,389.85)
Cost per tonne - 2020	$ 1,548
Cost per tonne - 2025	$ (470)

ACT Government – Analysis of mitigation actions to 2050: Analysis of measures
Electrification of ACT Buses

This measure assumes that ACT buses are electrified from 2025 on at the end of their 20th year in

Buses in today's ACT fleet	457	
Average operating life of ACT bus (years)	20	These figures were provided by the ACT government
Bus depots that can handle charging more than 1 Ebus	1	
Bus depots that need significant substation upgrades in district	3	
Emissions per existing bus (annual tCO2-e)	75.87	<- Figure provided by ACT Government (see table below)
AECOM abatement from carbon neutral buses, 2030 (tCO2-e)	39,802	
This suggests there are the carbon-free equivalent of 525 buses operating in 2030 in the reference case	525	
And the carbon-free equivalent of bus annual km of	28,748,285	km
Maintenance (Mahmoud 2016, broadly consistent with Monash LCA)		
Maintenance/km (diesel)	$0.47	<- Mahmoud (2016) reported the cost to be US$0.38/km, and exchange rate of 0.8
Ebus maintenance per km	$0.25	<- Mahmoud (2016) reported the cost to be US$0.20/km
Difference in maintenance per year	-$6,324,623	
Maintenance **savings** per Ebus	$12,047	
Operations (based on fuel)		
Diesel consumption per km (2017), litres	9,306,645	<- Figure provided by the ACT Government
Diesel consumption per km (2017), litres	0.458	l/km
Diesel consumption in 2030 avoided, litres	13,163,879	
Cost of diesel fuel	$1.20	per litre
Cost of avoided diesel	$15,803,855	
Energy used by electric buses	6.76	MJ/km <- See Mahmoud Table 6: Tank-to-wheel comparison Note this implies thermal efficiency of diesel engines is 40% (
Electricity consumed (MWh), based on km travelled	53,383	MWh
Cost of electricity	$5,789,763	<- We use the wholesale (ACT) rate for electricity so analysis is done for whole ACT not just ACT Gov
Difference in operations costs	-$10,014,091	
Operating cost **savings** per Ebus	$19,074	per year
Infrastructure (power system data from ACTEW/AGL, charging infrastructure from Mahmoud 2016)		
Cost of upgrading substations at bus depots	$15,000,000	per substation. Estimate provided by ACT Government
Cost of upgrades of 3 bus depots	$45,000,000	
Maintenance cost rate	5%	<- Energetics assumption
Annual cost of Ebus charging infrastructure	$2,250,000	

Upgrades to the bus fleet

We assume that the buses are replaced when they reach 20 years of age

Highlighted cells show instances when replacement is brought forward

Group	Number	Age into service	First replacement			First replacement		
			Scheduled year	Actual year	Type	Scheduled year	Actual year	Type
Group 1 : Currently Renault PR100.2 MK II	33	1993	2018	2018	Diesel	2038	2030	Electric
Group 2 : Currently Renault PR100.3	35	1993	2018	2018	Diesel	2038	2030	Electric
Group 3 : Currently Dennis Dart SLF	24	1997	2018	2018	Diesel	2038	2030	Electric
Group 4 : Currently IRISBUS AGORALINE	18	2005	2025	2025	Electric			
Group 5 : Currently SCANIA L94UB CB60	54	2004	2024	2024	Diesel	2044	2030	Electric
Group 6 : Currently MAN A69 18.310 HOCLNL	16	2008	2028	2028	Electric			
Group 7 : Currently SCANIA K320UB 14.5m 6 X 2*4 CB60	26	2010	2030	2030	Electric			
Group 8 : Currently MAN A69 18.320 HOUCL-R-NL	69	2009	2029	2029	Electric			
Group 9 : Currently SCANIA K360UA 6 X 2/2 CB80	33	2012	2032	2030	Electric			
Group 10 : Currently SCANIA K320UB CB80	49	2014	2034	2030	Electric			
Group 11 : Currently SCANIA-K320UB Bustech VST	20	2017	2037	2030	Electric			
Cost of a new electric bus	$350,000							
Incremental cost	$0	<- This parameter can be used to increase the cost of an electric bus over a diesel bus, and is available for sensitivity testir						

Cash flow

Item	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
Number of electric buses	18	18	18	34	123	457	457	457	
Installation of charging equipment including substations	-$45,000,000								
Brought forward purchase of new electric buses						-$107,800,000			
Avoided expenditure because the replacement of these buses was brought forward								$11,550,000	
Incremental cost of electric buses	$0	$0	$0	$0	$0	$0	$0	$0	
Annual maintenance savings	$216,844	$216,844	$216,844	$409,595	$1,481,769	$5,505,433	$5,505,433	$5,505,433	$5,505,
Annual operations costs savings	$343,340	$343,340	$343,340	$648,532	$2,346,159	$8,717,028	$8,717,028	$8,717,028	$8,717,
Infrastructure - chargers	-$2,250,000	-$2,250,000	-$2,250,000	-$2,250,000	-$2,250,000	-$2,250,000	-$2,250,000	-$2,250,000	-$2,250,
NET COST	-$46,689,816	-$1,689,816	-$1,689,816	-$1,191,874	$1,577,327	-$95,827,539	$11,972,461	$23,522,461	$11,972
NPV	$60,464,344								
Total additional abatement (kt CO2-e)	744,159								
Abatement cost	-$81.25	per tonne CO2-e							
Abatement in 2030	34.7	kt CO2-e							

ACT Government – Analysis of mitigation actions to 2050: Analysis of measures
Increase public transport mode share

The abatement measure is to implement measures to increase the model share of public transport by two percentage points

The analysis uses cost information from 2010 ACT Strategic Public Transport Network Plan Cost Benefit Analysis, 2015 Building Integrated Transport Network Active Travel and parking cost data to provide a more rigorous analysis on cost estimate for this measure.

Note: We have **excluded active transport from the analysis** because the table below showing the impact of parking fees on cycling shows that parking fees are expected to have a limited impact on any shift to active transport, and we lack the data to determine what impact investments in active transport infrastructure will have.

Cost of abatement analysis

In the following analysis, there are 4 components considered for the ACT's govt cash flow. Here is a list of assumptions underlying the projection of these components:
(a) Capital investment is made in full in 2021 and results in an immediate increase in utilisation of public transport.
(b) Results reported by AECOM in their transport study are used to establish the abatement due to the mode shifts.
All costs and savings are in nominal dollars.

Target increase in public transport use: 2 percentage points

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Abatement cost																
Impact of PT - reduction in emissions due to a 2 percentage point shift	23400	23400	23400	23400	23400	23400	23400	23400	23400	23400	23400	23400	23400	23400	23400	23400
Cash flow components																
1. Capital investment (additional bus and active transport infrastructure) to drive a 2 percentage point increase in public transport	$52,200,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2. Operating cost (extra bus services)	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000	$830,000
3. Allowance for lost productivity due to increased commuting time	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261	$8,478,261
4. Saving in petrol	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601	-$10,031,601
Net Cash Flow	-$51,476,660	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340	$723,340

NPV	-$40,505,387
Total additional abatement (t CO2-e)	468000
Abatement cost	$86.5
Additional abatement in 2030 (kt)	23

Summary of cost components

The following cost components correspond to the increase of 2 % in PT. The costs are in 2021 dollars as targeted between 2030 and 2040.

				Cost calculation details: Base cost	Impact of base	Target impact	Base cost year	Target year	Revised cost
Public Transport (More bus infrastructure)	$52,200,000	Capital	2010 ACT Strategic Public Transport Network Plan Cost Benefit Analysis shows that $147,155,000 is estimated to be the investment required to buses to bring PT mode share from 8% to 16%. This figure is scaled to give the cost for a 2 % increase in the mode share of PT, and inflated to 2021 dollars.	$153,000,000	8%	2%	2010	2021	$52,200,000
Public Transport (Extra operating cost for more bus services per year)	$830,000	On-going	2010 ACT Strategic Public Transport Network Plan Cost Benefit Analysis shows that an extra $2.7 million is required per year to operate bus services that aim to achieve an increase in PT mode share from 8% to 16%.This figure is scaled to give the cost for a 2 % increase in the mode share of PT, and inflated to 2021 dollars.	$2,700,000	8%	2%	2010	2021	$830,000
Allowance for lost productivity due to increased commuting time	$8,478,261		See **Allowance for lost productivity due to increased commuting time**						

Allowance for lost productivity due to increased commuting time

Total home to work (HTW) trips avoided	5,086,957	See *Parking cost calculation*	
Additional time spent traveling HTW via public transport	10	minutes per trip	
Total additional time spent travelling HTW	847,826	hours	
Lost productivity	$10	per hour	This figure is the amount of productivity the ACT economy loses because of the additional time spent travel to and from work.
Total cost	$8,478,261		

Summary of abatement cost and NPVs as a function of % PT increase target

% PT increase	Abatement cost	Abatement in 2030	NPV
1	86.3	12	(20,187,031)
2	86.5	23	(40,505,387)
3	86.3	35	#######
4	86.3	47	(80,783,653)
5	86.3	59	#######
6	86.4	70	#######
7	86.3	82	#######
8	86.3	94	(161,567,307)
9	86.4	105	#######
10	86.4	117	#######

Effect of an increase in the cost of parking

Note: These figures are not included in our financial analysis because the payments for parking are retained within the ACT

The following analysis draws the relationship between increasing in parking fee to the % increase in PT and AT transport mode share as targeted between 2030 and 2040.

Values in the highlighted cells are used in the NPV calculation and are also summarised above in "Summary of cost components"

Results			
Lost income to the ACT Government due to reduction in the use of the parking stations	$20,617,000	On-going	
Additional revenue from higher parking fee for the parking station capacity still used	$0	On-going	
>> Journey to work and emission data			
Typical journey to work distance (two way)	23	km	AECOM report
Car emission per km	200	g CO2-e/km	AECOM report
>> Parking cost calculation			
Abatement from 2 % increase in PT transport mode share	23,400	t CO2-e	AECOM report
Distance not driven by cars	117,000,000	km not driven by cars	
No. of journey to and from work not driven by cars	5,086,957	journeys	
Days per year for HTW travel	230		Assumes 30 days per year of leave of all kinds
No. of cars off the road	11,053	cars	
No. of parking spaces not used per year	10,000	spaces	If the number of cars off the road estimated is greater than the number of parking spaces then all parking spaces will be empty
Loss in parking revenue a year (2015 dollar)	$20,617,000		See *Parking spaces and cost data*
>> Parking spaces and cost data			
Total parking spaces controlled by the ACT	10,000	spaces	Received data from the ACT
Utilisation	30%		**Assume 30% of parking space available is currently used**
No. of parking spaces being used (and hence generating revenue)	3,000	spaces	
Extra annual revenue when parking price is raised by 6%	$360,000		Calculated based on data from budget paper 2015 where an increase of 6% in parking fee per year is estimated to increase parking revenue for the government by $360000 per year
Typical revenue from 1 parking spot per year (in 2015 dollars)	$1,778		
Typical revenue from 1 parking spot per year (in 2021 dollars)	$2,062		
Daily rate (for validity check, based on 6 days per week)	$5.70		
Increased in revenue due to the need to raise the fee from 1 parking spot per ye	$335.62		
Abatement due to mode shifts			
The data is taken from Tables 3 and 4 of the AECOM report	2030	2040	2050
Public transport mode share	16%	17%	18%
Emissions reduction due to additional PT	72273	85215	95593
Cycling mode share	7%	7.50%	8%
Walking mode share	7%	7.50%	8%
Emissions reduction due to additional cycling	55527	67616	77786
Impact of PT - reduction in emissions per percentage point shift	11700		
Impact of AT - reduction in emissions per percentage point shift	11100		
Required increase in parking fees			
The table below suggest that a parking fee rise of the order of 35% in 2016 will result in a 4.3 percentage point rise in the mode share of public transport			
Required rise in parking fees	16%	This is driven by increase in % point target	

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Best Consulting Engineering Firm with revenue < $50M

2015

Winner of Australian Business Award
Service Excellence
Marketing Excellence

2014

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Finalist
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Contact details

Energetics is a carbon neutral company

www.energetics.com.au

Sydney
Level 7, 132 Arthur St, North Sydney NSW 2060
PO Box 294 North Sydney NSW 2059
P: +61 2 9929 3911
F: +61 2 9929 3922

Perth
Level 3, 182 St Georges Tce, Perth WA 6000
P: +61 8 9429 6400
F: +61 2 9929 3922

Melbourne
Level 5, 190 Queen St, Melbourne VIC 3000
PO Box 652, CSW Melbourne VIC 8007
P: +61 3 9691 5500
F: +61 2 9929 3922

Brisbane
Level 12, 410 Queen St, Brisbane Qld 4000
P: +61 7 3230 8800
F: +61 2 9929 3922

Adelaide
Mitsubishi Administration Building
Level 1, 1 Tonsley Blvd, Adelaide SA 5042
P: +61 3 9691 5509
F: +61 2 9929 3922

abn 67 001 204 039
acn 001 204 039
afsl 329935