The Economics of Low Carbon Development:

Calgary, Canada

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Centre for Climate Change Economics and Policy

Report commissioned by

UNIVERSITY OF CALGARY

Calgary

The Economics of Low Carbon Development

Calgary, Canada

Today

3% of Calgary's GVA goes to energy expenditure each year.

3% of GDP leaks out of the economy

Tomorrow

Investing 0.6% of GDP p.a.

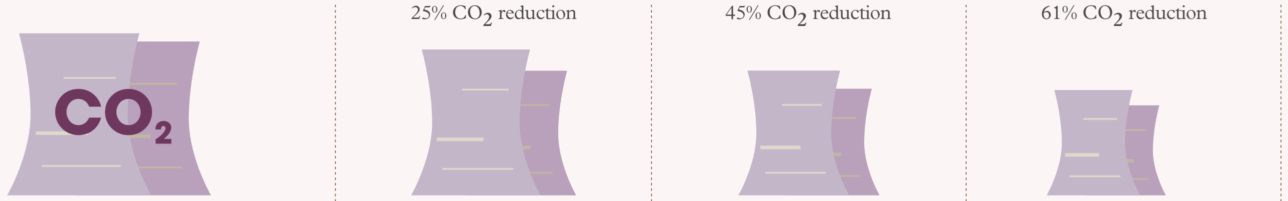
Leads to...

0.6% of GDP could be profitably invested every year through to 2030, or approximately $1 billion CND, to exploit economically attractive low carbon opportunities.

- **Energy**
  2030 annual energy bill could be cut by $1.7 billion, or $1100 per person
- **Employment**
  more than 70,000 job-years could be generated
- **Wider economic benefits**
  more energy security, improved resource efficiency, increased competitiveness
- **Wider social benefits**
  reductions in fuel poverty, improvements in health, and mobility

Potential to reduce CO_2 emissions

2018 | 2030



25% CO_2 reduction	45% CO_2 reduction	61% CO_2 reduction
Reduction with cost effective options.	Reduction with cost neutral options.	Reduction with all possible measures.

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Executive Summary

Introduction

Calgary is a city of more than one million people, with a GDP of more than $100 billion a year and total annual expenditure on energy of $2.6 billion a year. As a city, Calgary is committed to reduce its 2005 level of carbon emissions by 80% by 2050. This report examines the economic case for Calgary switching to a more energy efficient and lower carbon development path, and it provides both economic and broader evaluations on the desirability of different options and pathways. The evidence base generated is intended to provide policymakers, businesses and individuals in the city with reliable, locally relevant evidence so that they can take informed decisions on how best to switch to a lower carbon development path.

At a macro-level, the evidence shows that there is a strong economic case for switching to a lower carbon development path in the short to medium term, and that doing this would enable the City to meet its 2030 decarbonisation target, but it also highlights some significant longer term challenges in reaching Calgary's 2050 target. Preparing to meet these challenges in the short to medium term could significantly increase the chances and reduce the costs of meeting them in the longer term.

This report starts by looking at recent trends in energy use, energy bills and carbon emissions in Calgary, and it forecasts the cost and carbon implications of business-as-usual development in the city. To inform the discussion on how Calgary could shape its future energy use and carbon emissions, the report then assesses a long list of the measures that a range of actors in Calgary could take. Ranging from changing light bulbs to rebuilding offices, this analysis assesses the cost and carbon implications of single actions and of programmes of action that could be implemented across the city. Individually, many of these actions have only a small impact on energy use and carbon emissions. Collectively, however, the report finds that thousands of small actions, and some broader programmes, could generate massive cost savings and carbon emissions, with significant wider impacts in areas such as job creation, cleaner air, reduced energy poverty, and improved mobility[1].

This report highlights both the opportunity presented to Calgary, and the challenges that need to be overcome if the opportunity is to be taken. Low carbon measures can require large investments, coordination between policymakers, businesses, and individuals, and changes to the ways in which we live and work. However, the analysis shows that the benefits of many actions can far outweigh the costs – a low carbon future for Calgary will not just improve the global climate, but bring economic and social benefits to the lives of Calgarians.

[1] Research from a large set of global cities suggests that 14-24% of urban GHG emissions can typically be reduced with actions that generate net economic returns to investors (Gouldson et al 2015).

The Economics of Low Carbon Development:

Our Approach

Drawing on data from a wide range of sources and technical expertise at the University of Leeds and the University of Calgary, our approach is to develop a robust model of the energy use and emissions of the different sectors across the city. Taking into account planned investments and policies, including at the national and provincial levels, our focus is on the opportunity for action based on currently available technologies within the city. Our work is focused on small scale renewables and energy efficiency measures that could be adopted across the residential, commercial, transportation, waste and industrial sectors. Our mitigation estimates are made using established emissions protocols that consider only energy-use within the city – including both fuels and electricity consumed in Calgary. Technically, these emissions are known as 'scope 1' and 'scope 2' emissions - so-called 'scope 3' emissions that are embedded in the goods and services that are imported into or exported from the city are excluded from our analysis.

Reading this Report

The report provides estimates of the cost and carbon case for low carbon investments in Calgary. Economic calculations include all direct costs, such as capital costs, running costs and energy expenditure, but not indirect costs or benefits, including economic spillovers, multiplier effects such as cultural and behavioural shifts, or co-benefits such as improved public health. In all cases, we consider the direct economic savings stemming from reduced energy consumption but not the knock-on indirect or induced implications that may be associated with a measure.

All investment figures are based on evaluations of performance over the lifetime of measures. Payback periods are determined using the average economic savings over the lifetime of the investment. Calculations assess the realistic technical potential of a measure – taking into account the installed rather than the theoretical performance of a measure. This report covers a large set of actions that could be implemented in Calgary, but it does not include every possible action. Renewable natural gas, district energy schemes, autonomous vehicles and some behavioural conservation measures are not considered in the analysis due to challenges finding necessary data and a high degree of uncertainty around costs and performance. However, future analysis that evaluates these options could be readily integrated into the outputs of this analysis. The aggregated economic case that is presented relates to the costs and benefits that fall within the city as a whole. It is important to note that these costs and benefits may not be evenly distributed, and that distributional issues (and the presence of winners and losers in the city) can be critically important.

Finally, it is important to point out that the findings and recommendations from this analysis come from the University of Leeds and the University of Calgary, and not The City of Calgary. Further details of the methods and sources can be found in the Climate Smart Cities Reference Document[2].

[2] Climate Smart Cities Calgary Reference Document (2018). Available from www.climatesmartcities.org

Calgary's GHG Emissions: In Decline, but Far Above Calgary's Targets

As shown in Figure 1, our baseline analysis of existing policies and trends in the economy suggest that GHG emissions have peaked in Calgary and are forecast to decline by a small amount through to 2050. However, the analysis predicts that without futher actions GHG emissions in the city will be:

-24% above The City of Calgary's target of reducing Calgary's emissions by 20% below 2005 levels by 2020. This means Calgary will be emitting more than 3Mt CO2e annually in excess of targets, or a reduction of more than 2 tonnes CO2e per person would be required to close the gap.

-300% above The City of Calgary's target of reducing Calgary's emissions by 80% below 2005 levels by 2050. This means Calgary will be emitting nearly 9.5 Mt CO2e in excess of targets, or a reduction of approximately 4.5 tonnes CO2e per person would be required to close the gap.

This baseline analysis assumes a continuation of recent trends in Calgary's population, economy, building stock and electricity grid, and some planned changes in policies. Key assumptions are listed in Table 1.

Figure 1: GHG emissions under the baseline scenario

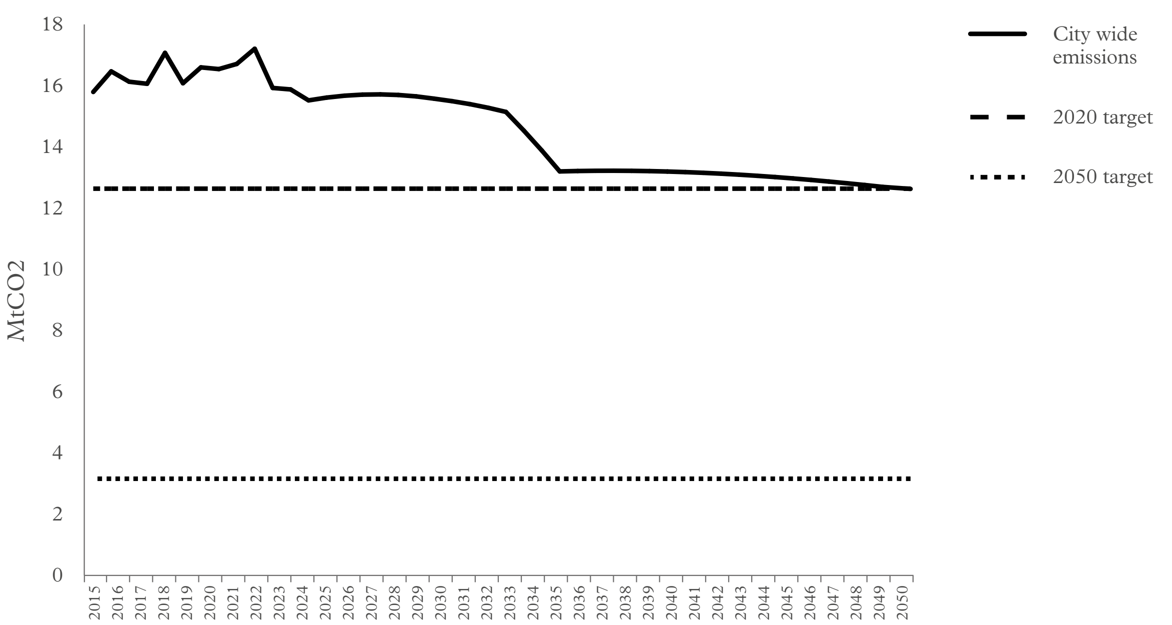


Table 1: Key baseline data

GDP growth: 2.4%	Energy prices growth (average across fuels): 3.3%
Population growth: 1.3%	Carbon price of $50 by 2022
Full implementation of the Municipal Development Plan (MDP): land base growing 27.6% from 2009-2070 rather than 45.5% under the baseline scenario.	Full implementation of the Calgary Transportation Plan (CTP): Green line built and a large number of smaller improvements to the public and private transport network.
Provincial actions: (BNI) Energy Savings Rebates Program, Residential Solar Program, Residenital No-cost Energy Savings Program, Residential Retail Products Program	Electricity grid: 0.64 tonnes/MWh in 2017, to 0.30 tonnes/MWh in 2030 and 0.13 tonnes/MWh in 2050

By source, the residential, commercial, and industrial sectors currently comprise more than 70% of city-wide emissions. Looking forward to 2050, emissions in all sectors will decline slightly, largely due to a decarbonizing of the electricity grid, with the exception of the transportation sector which will see an increase in its share of emissions (Figure 2).

The Potential for Reducing Carbon Emissions and Generating Economic Returns

When considering the prospects for low carbon development to alter these business as usual trends, the results of the analysis show that Calgary could substantially reduce energy use, energy costs and emissions. As shown in Figure 3, between 2017 and 2050 we predict that Calgary could reduce its baseline emissions by:

— 41% through cost effective investments that would pay for themselves (at an 8% real interest or discount rate) quickly before providing further profits over their lifetime. This would require cumulative investment of $12.4 billion and generate average savings of up to $4.2 billion per year. Using net present values, the investment is paid back in 3 years.

—70% through cost neutral investments[3] that could be paid for at no net cost to the city's economy if the benefits from cost effective measures were captured and re-invested in further low carbon measures. This would require cumulative investment of $100.4 billion, generating savings of up to $5.7 billion per year. Using net present values, the investment is paid back in 17 years with savings continuing over the lifetime of the measures still in place.

— 77% with the exploitation of all of the realistic potential of the different measures considered. This would require cumulative investment of $177 billion, generating savings of up up to $7.2 billion per year. Using net present values, the investment is paid back in 24 years with savings continuing over the lifetime of the measures still in place.

[3] Note on the scenarios or pathways:
Cost effective: The set of all measures that generate a positive economic return
Cost neutral: The set of measures that generates the largest savings in GHG emissions while maintaining an indicated rate of return across all measures greater than zero
Technical potential: The set of measures that generates the largest savings in GHG emissions

Figure 2: Emissions in Calgary by sector

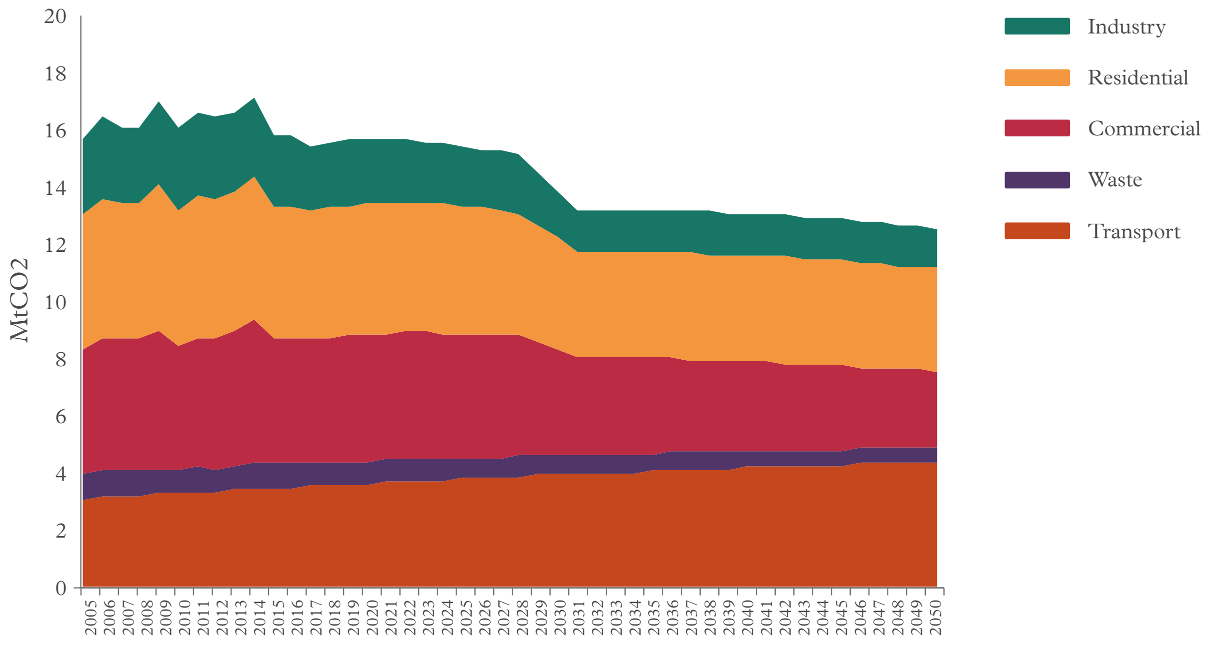
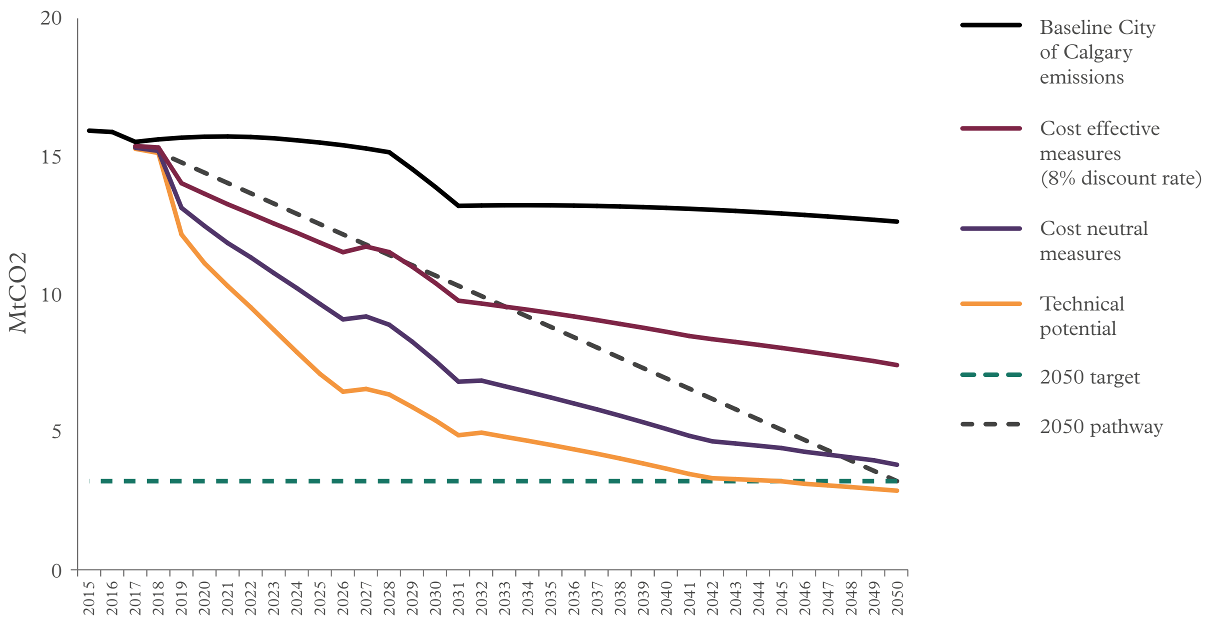


Figure 3: Calgary's potential future emissions under the baseline and carbon reduction scenarios



Impact on Energy Bills

We find that Calgary currently spends $2.6 billion on energy each year, or 3% of all money earned in the city. By 2030 this could rise to $6 billion and 4% of all money earned in the city through expected increases in energy prices and the growth of economic activity. Reducing carbon emissions directly translates into reduced energy use and energy bills across the city.

—With cumulative investment in cost effective measures of $12.4 billion through to 2050, the 2030 annual energy bill could be cut by $1.7 billion (29%), or $1100 per person per year.

—With cumulative investment in cost neutral measures of $100.4 billion through 2050, the 2030 energy bill could be cut by $2.55 billion (42%), or $1600 per person per year.

—With cumulative investment to exploit all of the realistic potential of $177 billion through 2050 the 2030 energy bill could be cut by $3.1 billion (54%), or $2100 per person per year.

Residents and businesses within the city of Calgary could therefore significantly enhance their energy security through investments in energy efficiency and low carbon options.

The Most Cost and Carbon Effective Options

Targetted actions can generate substantial impacts on future carbon emissions. Table 2 shows the most carbon effective actions – those actions that could save the most tonnes of emissions – over their lifetime. For sectors that could adopt different levels of action, the results are presented in a range from the minimum to maximum impact. For example, replacing only heavy vehicles with electic vehicles would save 7Mt CO2, but replacing the entire fleet of vehicles in Calgary could save 65Mt CO2.

A number of actions reduce carbon emissions while generating net economic returns at an 8% real discount rate. Table 3 presents the top 10 actions ranked by the cost per tonne of emissions reduction. Note, negative figures (in brackets) mean that a measure incurs a negative cost – or in other words that it generates a positive economic return – for every tonne of carbon saved. Only measures that save more than 1Mt of CO2 are presented.

A number of measures are found in both tables 2 and 3, indicating that they are both cost and carbon effective. These include land-use measures that result in modest increases in urban density, electric and hybrid cars, and low level retrofits across the commercial and residential sectors.

Table 2: The most carbon effective options

Rank	Sector	Subsector	Intervention (s)	Carbon savings (Mt CO2 over lifetime)
1	Residential	Single family homes (existing)	Zero Energy building, High Performance-Based Standard, Upgrade to mid Performance-Based Standard, Upgrade to code	11-86Mt
2	Transport	Private vehicles (light, medium and heavy)	Electric vehicles	7-65Mt
3	Residential	Single family homes (new)	Zero Energy building, high Performance-Based Standard, Upgrade to mid Performance-Based Standard, Code plus efficient lights and appliances	22-57Mt
4	Commercial	Retail (new)	New 1 (AEDG 30), New 2 (AEDG 50)	16-26Mt
5	Transport		Biofuel (B20)	17Mt
6	Waste		Energy from waste (CHP and electricity), incineration, landfill gas utilization	13-15Mt
7	Land-use	Buildings and transportation	MDP and MDP+	7-12Mt
8	Transport		Increased parking levies	12Mt
9	Transport		Reduced car ownership	8Mt
10	Residential	Townhouses (existing)	Zero Energy building, high Performance-Based Standard, Upgrade to mid Performance-Based Standard, Code plus efficient lights and appliances	2-22Mt

Table 3: The most cost effective options

Rank	Sector	Subsector	Intervention (s)	Cost per tonne ($ per tonne carbon saved)
1	Land-use		MDP and MDP+	($300-325)
2	Transport	Private vehicles	Increasing parking levies	($270)
3	Transport	Goods transport	Electric goods vehicles (light, medium and heavy)	($225-245)
4	Transport	Private vehicles	Hybrid private vehicles	($70) to ($140)
5	Transport	Private vehicles	Electric private vehicles	($50-110)
6	Residential	Existing apartments, townhouses and single family homes	Retrofit 1: Efficient lights and appliances	($60-80)
7	Commercial	Retail/Offices/ Warehouses	Shallow retrofit	($40-60)
8	Residential	New apartments, townhomes, and single family homes	Code + Efficient lights and appliances	($30) to ($40)
9	Commercial	Existing retail	Moderate-Deep Retrofit	($20)
10	Commercial	New offices	AEDG 30%-50%	($10-20)

[4] For a small number of actions in the waste sector, energy use increases when carbon emissions decline. Across the other sectors and actions within this report, energy use reductions lead directly to GHG emissions savings.

Table 4: Impacts on Employment by scenario

	Transportation	Industry (s)	Waste	Residential	Commercial	Distributed energy	Total
Cost effective investments	0	1	-3	50	23	0	71
Cost neutral investments	291	4	3	427	69	67	860
Technical potential investments	664	7	0	1124	69	67	1931

Impacts on Employment

The analysis indicates that investments in low carbon actions in Calgary could generate substantial employment opportuntites. Table 4 presents these impacts by sector and scenario in 'job-years', which are the number of years of full-time employment generated from an investment. Results are calculated using employment intensity multipliers that relate every $1 million of investment to a number of jobs created. For example, in the residential sector it is assumed that every $1 million in investment generates 13 job-years of employment[5].

In summary, we find that:

- More than 70,000 job-years could be generated by investment in cost-effective low carbon actions.
- Nearly 860,000 job-years could be generated by investing in cost neutral options.
- Almost 2 million job-years could be generated by investing in all of the options at their maximum potential in this report.

[5] Employment generation numbers should be treated with a high degree of caution. While a substantial body of research in North America and Europe establishes that investments in energy efficiency and low carbon development can generate increased employment – even after considering the jobs lost in other industries from diverted investment – the impacts of many types of investments are uncertain, especially for the cost neutral and technical potential scenarios. Electric vehicles for example are assumed to have a zero net impact on employment in this analysis – although arguments can be made both for job creation and job losses, the net impact is uncertain as they could require less maintenance, thereby leading to job losses in auto repairs, but lower transportation costs could also stimulate the economy and help to generate jobs in many sectors . The impacts of investments on employment are also highly dependant on economic conditions. If unemployment is relatively high, the potential for net job creation is relatively large. However, as the economy reaches full employment, the number of net jobs created may be smaller. The net impacts of investments will also be affected by technical change, which typically reduces employment impacts.

Wider Social, Environmental and Economic Impacts:

Results from a Multi-Criteria Analysis

The presence of an economic or carbon case for investment, while frequently necessary, is not a sufficient basis for action. Investments are typically made with a range of other criteria such as improved public health or enhanced mobility as the primary motivation for action.

In order to capture the public's perception of the pros and cons of the actions investigated by this analysis, a multi-criteria analysis was conducted based on an on-lone survey completed by 262 participants[6]. The results of this survey can guide further engagement with stakeholders to understand the most effective and desireable programs and policies.

Respondents to the survey were asked to rank the desirability of various measures against seven criteria:

- Economic development and impact
- Environmental co-benefits
- Accessibility and equity
- Human health and well-being
- Capacity for implementation
- Political acceptability
- Public acceptability

The results are summarised in Table 5 and 6. Scores greater than zero indicate that respondents on average foresee a net positive social/economic/environmental impact from a measure. Zero indicates that respondents anticipate a net neutral impact and negative scores indicate an expected detrimental impact. Tabe 5 presents the measures that had the top rank against all criteria, and table 6 presents those with the bottom rank.

The results show that respondents saw the potential for positive impacts across a range of actions in different sectors. Notably, the actions which received the highest scores tended to be relatively less invasive or disruptive and lower cost compared with other measures in each sector. While solar PV had one of the highest overall scores, a more specific scenario involving solar PV showed a net negative impression of this measure. This suggests that the specific approach to implementation can be very important in shaping public perceptions of different low carbon options.

However, the results also show that respondents anticipated a net negative impact from some measures, with approximately 1 in 5 of the measures assessed receiving a negative score. Measures in the waste and transportation sectors are is proportionately represented in this category. This table also shows that more expensive and invasive measures received significantly lower scores. This suggests that respondents generally preferred cheaper options that could be more readily assimilated into existing structures.

These findings corroborate well with similar multicriteria analyses conducted elsewhere, as well as wider literature on multicriteria analyses of low carbon interventions. Especially in the early stages of project planning, where specific details on policy approaches and wider impacts of measures are limited, respondents are more likely to react negatively to the most disruptive approaches. Identifying these measures early on in the process of decision making is critical for informing ongoing stakeholder engagements and the eventual consideration of policy options.

[6] It should be emphasised that the subset of the Calgary population participating in the survey was not representative. Respondents, were on average relatively older and had spent a longer period of time in receiving academic qualifications, and males were over-represented. Further, it should be noted that results reflect public opinion on the desirability of different low carbon measures without extensive information being provided. Nonetheless, these results provide an indication of where Calgarian's see potential for positive and negative social, environmental, and economic impacts from the measures investigated.

Table 5: Thousands of job-years created by investment in each sector

Sector	Measure	Score
Waste	Prevention (5-10% target)	24.5
Distributed energy	Solar PV	17.4
Residential	New Low – Upgrade lighting and appliances	15.5
Waste	Land-fill gas utilization	15.3
Residential	Retrofit Low – Upgrade to current building code	13.6
Commercial	Retrofit 1 – Shallow Retrofit	14.3
Transportation	Increased cycling and walking to work	13.0
Residential	New Medium – Upgrade to mid-optimal insulation	12.3
Commercial	New 1 - 'Shallow' Standard For Buildings	12.4
Land-use	Best practices in green field developments	11.0

Table 6: 10 measures that received the highest aggregated scores across different criteria

Sector	Measure	Score
Waste	Incineration	-12.4
Transportation	Increasing parking levies	-11.1
Transportation	Reduced car ownership (20-40% target)	-8.0
Transportation	Biofuel (B20)	-7.1
Waste	Landfill gas flaring	-5.1
Transportation	Hybrid vehicles (5-50% target by 2030)	-1.0
Residential	Retrofit Very High – Addition of solar PV array	-0.9
Transportation	Electric vehicles (5-50% target by 2030)	-0.9
Distributed energy	Distributed Wind	0.3
Transportation	Compressed natural gas heavy vehicle transportation	0.4

Conclusions

A low carbon future for Calgary can also be a prosperous future. The analysis shows that there is a strong economic case for Calgary to pursue an ambitious and cost-effective low carbon development path that is consistent with its 2050 target for decarbonisation, at least until the early 2030s (see the cost-effective pathway in Figure 3). Although this would require total investments of over $12 billion, the analysis shows that in aggregate these investments would pay for themselves within 3 years before generating net returns of $1.7 billion per year in the city by 2030. These investments would also create more than 70,000 years of extra employment in the city. The opportunity for cost-effective forms of low carbon development should therefore be seen as an opportunity to secure a very significant economic benefit for the city.

It is important to note that a significant proportion of the investment required to enable a switch to this lower carbon development path could occur autonomously – for example where organisations or individuals invest in reducing their own energy use and carbon emissions in order to realise the associated benefits. A further proportion could be stimulated through new forms of policy such as improved building standards or requirements for decentralised energy to be integrated into new developments. More still could be realised through policy 'nudging' developments that would have happened anyway towards a more energy efficient and lower carbon path. Nonetheless, some of the required investment would undoubtedly need to be raised from different investors. Innovative ways of securing and deploying such investments - such as green bonds or revolving funds - could make this level of investment more achievable and ensure that more of the benefits of the investments are retained by actors within the city. The analysis also suggests though that considering only the cost-effective options for low carbon development will mean that the city departs from the pathway towards its 2050 target in the early 2030s – at least with current technologies and under current conditions (again see Figure 3). Of course, this point of departure could be delayed if new technologies come on stream or if the cost-effectiveness of currently available technologies improves before then. This seems likely to some extent – and it could be encouraged through different forms of policy in various instances - but it seems very unlikely that these advances would completely close the gap between the cost-effective pathway and the path towards the 2050 target as depicted in Figure 3.

In theory, the gap between the cost-effective pathway and the path towards the 2050 target could also be closed if the city (or organisations within it) found a way of capturing and recycling some of the savings from the more cost-effective options and using these to subsidise investments in the less cost-effective options. This could be facilitated through innovative measures such as a city-level revolving fund. If such a fund had complete coverage and near perfect efficiency, the analysis shows that the city could get very close to its 2050 target at no net cost, even with current technologies (see the cost-neutral pathway in Figure 3). The incentives for developing such a fund, or something that approximates it, are huge. The cost-neutral pathway would see investments of over $100 billion creating 800,000 years of extra employment in the city. The prospect of that scale of economic stimulus in the city could be enough to trigger significant innovations in low carbon financing.

The results therefore demonstrate that Calgary could meet and exceed its contribution to national carbon reduction targets. At a national scale, Canada has committed to cutting emissions 30% by 2030 from 2005 levels. The analysis shows that Calgary could reduce its emissions 35% below its 2005 levels by 2030 by applying only cost-effective actions, and by 53% if the returns from cost effective actions were reinvested[7]. Climate action is therefore not just an opportunity for economic, social and environmental returns, but an opportunity for Calgary to showcase itself as a leader in the low carbon economy – one of the fastest growing sectors in OECD countries.

The analysis in this report makes a case for Calgary to be a leader in the low carbon economy. It also offers some guidance on most cost and carbon effective and publically acceptable ways of assuming this leadership position. However, it is important to emphasize that the economic lens through which much of this analysis has been conducted provides only a limited perspective on the rationale for climate action in Calgary. Clearly the case for action must be viewed in the context of a much wider set of criteria that consider the future of the city in broader terms. But the main conclusion of the report is that the shift towards a lower carbon development path for Calgary cannot be dismissed on technical or economic grounds – an economically and technologically viable transition to a low carbon Calgary is entirely possible.

[7] This analysis assumes that Calgary's contribution to national emissions reduction targets should be the same proportion of current emissions. In reality, land-use change in Canada is likely to significantly reduce the emissions reductions required from urban centres.

Chapter 1.0
Introduction

The Environmental and Policy Context: The Need for Low Carbon Cities

Canada has the potential to be a world leader in efforts to mitigate climate change. Government bodies at the federal, provincial, and municipal levels are taking actions to reduce carbon emissions, promote clean and renewable energies, and create jobs.

At the federal level, the main initiative for towards greenhouse gas (GHG) emissions reduction is a push for a provincial carbon tax. The federal government provides a framework that provinces can follow to either set up a cap-and-trade system or tax carbon emissions directly, with a minimum tax of $10 per tonne emitted in 2018, rising $10 each year to $50 per tonne in 2022. Further to this, the federal government is promoting the construction of and conversion to more energy efficient buildings with subsidies for clean buildings and the promotion of ENERGYSTAR rated appliances; clean transportation with the clean fuel standard, investments in electric vehicle charging stations, and expansion of public transit systems; clean electricity with the phasing out of coal-fired electricity generation; as well as investment in innovation and new technologies which work towards Canada's climate goals.

Due to the diverse range of resources, industries, and populations in the Canadian provinces, specific climate change mitigation policies are largely decided at the provincial level. As one of the major emitters in Canada, Alberta has a particular responsibility to monitor and reduce emissions and the policies in place are a reflection of this. Alberta instituted a carbon tax of $20 per tonne emitted in 2017 and will increase this to $30 per tonne in 2018, with options to continue increasing the price to $50 based on results over the first two years of implementation.

Alberta is also moving towards lowering the emissions from electricity production, eliminating coal production and shifting to natural gas based generation for 70% of the province's electricity, with an additional 30% renewable energy by the year 2030. Currently, almost all of Alberta's renewable energy comes from wind production, with no major solar generation. The shift to renewables will involve significant expansion of wind power, as well as small scale solar installed in urban and other populated areas. The climate leadership plan in Alberta hopes to accomplish these goals while maintaining a strong economy that makes best use of the resources available in the province. This includes continued development of the Alberta oil sands, with strict caps on total emissions coming from the oil sands, and the use of natural gas to support the electricity grid.

At the municipal level, the city of Calgary employs a climate program that focuses on adaptation to the effects of climate change and mitigation of climate change by reducing energy use and greenhouse gas emissions city-wide in the residential, commercial, industrial, transportation and waste sectors. Calgary has a target to reduce GHG emissions to 20% below 2005 levels by 2020 and 80% below 2005 levels by 2050. Despite the provincial goals to lower the emissions of the electricity grid and to shift shift towards renewables, the city will not meet its emissions targets without the implementation of additional actions. This report considers the economic case for adopting these additional actions, and the contribution that different options could make.

Chapter 2.0
Approach to the Analysis

To conduct the main assessment of the cost and carbon effectiveness of different low carbon options, a six stage approach was applied.

a) Identifying applicable low carbon measures

Information on the cost, performance, and applicability of a range of low carbon options was collected from a range of sources, including The City of Calgary, The Pembina Institute, the International Energy Agency (IEA), The Passive House Institute and Industry Canada. Insights from these sources were supplemented with evidence on the range of options considered in previous Climate Smart Cites studies to generate a long list of options to be evaluated. This long-list was reviewed and refined by stakeholder groups with expertise in each of the sectors being assessed. A short-list of options that could be applied within the city was then finalised. This focused on the technical opportunities for reducing emissions, rather than on policy or behavioural actions.

b) Evaluating the cost and carbon performance of each applicable measure

Drawing on the data sources outlined above, information on the costs of adopting one unit of each measure and the energy (and hence the financial and carbon) savings that can be expected over the lifetime of that measure was collated. The unit of analysis varies by sector. In the residential, commercial, and industrial sectors, we consider costs per house, unit of floor space or unit of energy saved respectively. In the transportation sector, public transportation measures are assessed by considering full-project appraisals, while private transportation measures (e.g. electric cars) are assessed at the level of individual vehicles. The costs considered include capital costs, running and maintenance costs. Actual or potential incentives designed to encourage take up of small scale renewable or energy efficiency measures, such as feed-in tariffs, are not incorporated in the input data we have sourced.

Future energy costs are based on data provided by the City of Calgary, which anticipate energy prices rising approximately 270% over the period from 2017 to 2050. The carbon intensity of the electricity grid is based on modelling estimates completed by the team that anticipate the provincial grid declining in carbon intensity from 0.64 tonnes/MWh today, to 0.30 tonnes/MWh in 2030 and 0.13 tonnes/MWh in 2050.

c) Understanding the potential for the deployment of different measures in Calgary

In order to calculate the potential for energy and emissions savings, the actions identified above need to be linked with information on the size, composition and energy efficiency of the residential, commercial, industrial, waste and transportation sectors.

For the residential sector, data on the existing and future housing stock was obtained from the City of Calgary. Excluding mobile homes, this data provides information on three housing types: single family (detached) homes, townhouses, and apartments. Houses built after 2017 are assumed to built to the current building code, while for existing homes a representative home is built using modelling software. Measures were then designed that apply to each of these housing types.

For the commercial sector, data on the existing and future stock of offices, retail establishments and warehouses was provided by the City of Calgary. In a similar fashion as the residential sector, new buildings are assumed to be built to the existing code and for existing buildings a representative office/retail/warehouse was designed using modelling software. Measures were then designed that apply to each of these building types.

For industry, information on different industrial sectors was obtained from Alberta level Industry Canada data. The oil and gas sector, as well as several subindustries identified during stakeholder consultations as not existing in Calgary were excluded from analysis. Analysis therefore focused on cross-cutting industrial measures for boilers/steam systems, furnaces/process heaters, refrigeration, and motor driven equipment. To these IEA industry-wide measures are applied. It is assumed that measures with an Internal Rate of Return (IRR) equal to or greater than 100% have already been taken, while measures with less than 100% IRR are still available for investment.

d) Understanding background trends, developing baselines and scenarios for deployment

The analysis focused on the adoption of low carbon measures at rates over and above background trends included in a baseline or business as usual scenario. This baseline scenario is projected out to 2050 by combining (1) data on historical trends in Calgary's affluence, energy use and carbon emissions, (2) population and economic growth projections, and (3) provincial level carbon emissions and energy price projections to 2050. We focus on production-based emissions by considering the energy used and carbon emitted both directly within the city (Scope 1 emissions) and indirectly due the consumption of electricity within the city (Scope 2 emissions).

The 'baseline scenario' assumes continuation of trends in Calgary's population, economy, building stock and electricity grid, and some planned changes in policies. Key assumptions are listed in Table 7.

Table 7: 10 measures that received the highest aggregated scores across different criteria

GDP growth: 2.4%	Energy prices growth (annual average across fuels): 3.3%
Population growth: 1.3%	Carbon price of $50 by 2022
Full implementation of the Municipal Development Plan (MDP)	Full implementation of the Calgary Transportation Plan (CTP)
Provincial actions: (BNI) Energy Savings Rebates Program, Residential Solar Program, Residenital No-cost Energy Savings Program, Residential Retail Products Program	Electricity grid: 0.64 tonnes/MWh in 2017, to 0.30 tonnes/MWh in 2030 and 0.13 tonnes/MWh in 2050
Transportation	Biofuel (B20)
Waste	Landfill gas flaring
Transportation	Hybrid vehicles (5-50% target by 2030)
Residential	Retrofit Very High – Addition of solar PV array
Transportation	Electric vehicles (5-50% target by 2030)
Distributed energy	Distributed Wind
Transportation	Compressed natural gas heavy vehicle transportation

e) Identifying investment needs, financial returns and carbon savings for decarbonisation scenarios

Aggregated investment needs, payback periods and carbon savings are assessed under three different investment scenarios or pathways:

Cost-effective – in this scenario only those measures that generate net economic returns are deployed. For this we adopt a commercially realistic real (i.e. excluding inflation) interest rate of 8%. In this scenario, if two measures are mutually exclusive, that measure which has the highest net present value is deployed.

Cost-neutral – in this scenario, we assume deployment of all measures that could be afforded if the benefits from the cost effective measures were captured and reinvested in further low carbon options. This scenario achieves the largest carbon savings with the IRR of the scenario remaining greater than zero.

Technical potential – in this scenario the highest emission saving measures are employed, regardless of costs. The only limitation on this scenario is the range of measures considered and any interactions between them. In the housing, for example, existing homes are restricted to a single retrofit over the period between 2017 and 2050.

f) Developing league tables of the most cost and carbon effective measures

Having completed calculations of the costs and benefits of each option, league tables of the most cost and carbon effective measures for the residential, industrial, commercial, transportation and waste sectors and for the city as a whole are developed (see Appendices A and B). These tables show a ranking of options where those options with the stongest case are presented at the top. In these tables actions are assessed independently of each other and of actions in other sectors.

g) Developing and Implementing a Multi-Criteria Analysis

A multi-criteria analysis was conducted to understand Calgarian's perception of the wider social, environmental and economic case for these actions. A three step process was undertaken.

a) Criteria development

First, discussions were held with sector specific working groups to understand the criteria necessary for an action to achieve social license in the city of Calgary.

To aid in these discussions, a longlist of possible criteria, drawn from the academic literature, was presented to participants and individual members were asked to select their top 5. Information from these working groups was then used to develop a set of 7 criteria that captured the broad set of interests and concerns raised in the working groups. These criteria were:

- Economic development and impact
- Environmental co-benefits
- Accessibility and equity
- Human health and well-being
- Capacity for implementation
- Political acceptability
- Public acceptability

These criteria were not the top 7 raised by the working groups but were seleted by the research team and City of Calgary as representing the most inclusive set of criteria with which to conduct the survey.

b) Survey development

An online survey was then developed in order to capture the largest number of responses. SurveyMonkey software was used and a survey was designed that included two key components. The first of these was a weighting procedure. For each of the criteria respondents were asked to provide a score from 1 to 5, with 1 indicating that the respondent attached a low level of importance to the criteria and 5 a high level of importance. Respondents were then asked to rank individual low carbon options with a score from 1 to 5 indicating the extent to which the option fulfilled each criteria, with a score of 1indicating a low level and 5 a high level. Rankings were made ithout any further information on the cost or carbon case for investment as established by the modelling, on the approach to implementation of the measyre or on potential social, environmental or economics impacts. These rankings therefore reveal respondents first impressions of the different options based on their own experiences and knowledge.

Several changes were made to the list of measures in order to shorten the length of the online survey. In the residential and commercial sectors actions were presented across building types. This means that a retrofit of a specific type was considered for single family homes, townhouses and apartments at the same time. Similarly, a new building standard for commercial buildings was considered for offices, retail establishments and warehouses at the same time. Several measures were removed from the analysis to avoid confusion amongst respondents[8], and some others were added to the analysis that were not included in the economic assessment[9]. The industry section was not included in the MCA due to the highly technical nature of interventions. While reducing some of the granularity of the results, this reduced the length of the survey substantially which increased participation rates and allowed for results to focus on some of the higher level findings. The on online survey was conducted between 26/07/2017 and 26/08/2017 and was completed by 261 participants.

c) Survey analysis and presentation

In order to present the key results, and to maintain the anonymity of the respondents, results are aggregated and presented as weighted averages. This means that the results represent a combination of the value of each criteria, as indicated by each respondent, and the score they gave for each measure-criteria combination. For presentation purposes, results have also been rebased. During the survey respondents were asked to rank measures from 1 to 5, with 1 indicating a 'very poor' performance and 5 representing a 'very good' performance, according to the criteria. Here, 3 has been taken from each of the average results so that negative results indicate a 'poor', or 'very performance', and positive numbers show a 'positive' or 'very positive' performance.

[8] Discussions with working group members led the team to believe that asking about measures in the residential sector with and without heat-pumps would lead to confusion due to uncertainty around the type of heat pump and its operating efficiency. Further, preliminary modelling results showed the configuration without heat pumps performed better both in economic and carbon terms. Heat pump options were therefore not included in the list presented in the MCA.

[9] Several measures were also added to the list of actions to be included in the MCA that were not modelled for their economic and carbon case. These include several distributed energy options. While the research team was not able to complete economic and carbon modelling of these options they are areas of potential further research.

Chapter 3.0
Key Findings

Baseline Emissions: Sources and Targets

Our analysis shows that production-based (scope 1 and 2) carbon emissions peaked in Calgary in 2009. Since then, as a result of a decarbonising electricity grid, improving vehicle efficiencies and reduced energy use in homes and offices, emissions have declined by more than 9%. However, the rate of decline is expected to diminish in the near future, and we predict that without further actions at the national, provincial of local levels Calgary will not meet its carbon reduction targets. We forecast that Calgary's 2020 target of reducing emissions 20% based on a 2005 baseline will be missed by approximately 3 Mt CO2e, and the 2050 target of reducing emissions 80% based on a 2005 baseline will be missed by 9.5 Mt CO2e.

Figure 5 presents the composition of emissions by sectoral source. In 2017 the residential sector represented the largest sectoral contribution to emissions, followed by the commercial and transportation sectors. By 2050, we forecast that emissions from transportation will have grown significantly in both absolute and relative terms, making it the largest source of emissions as vehicle kilometres per capita and a rising population outweigh the impacts of improving vehicle efficiencies.

Figure 4: Baseline emissions and targets

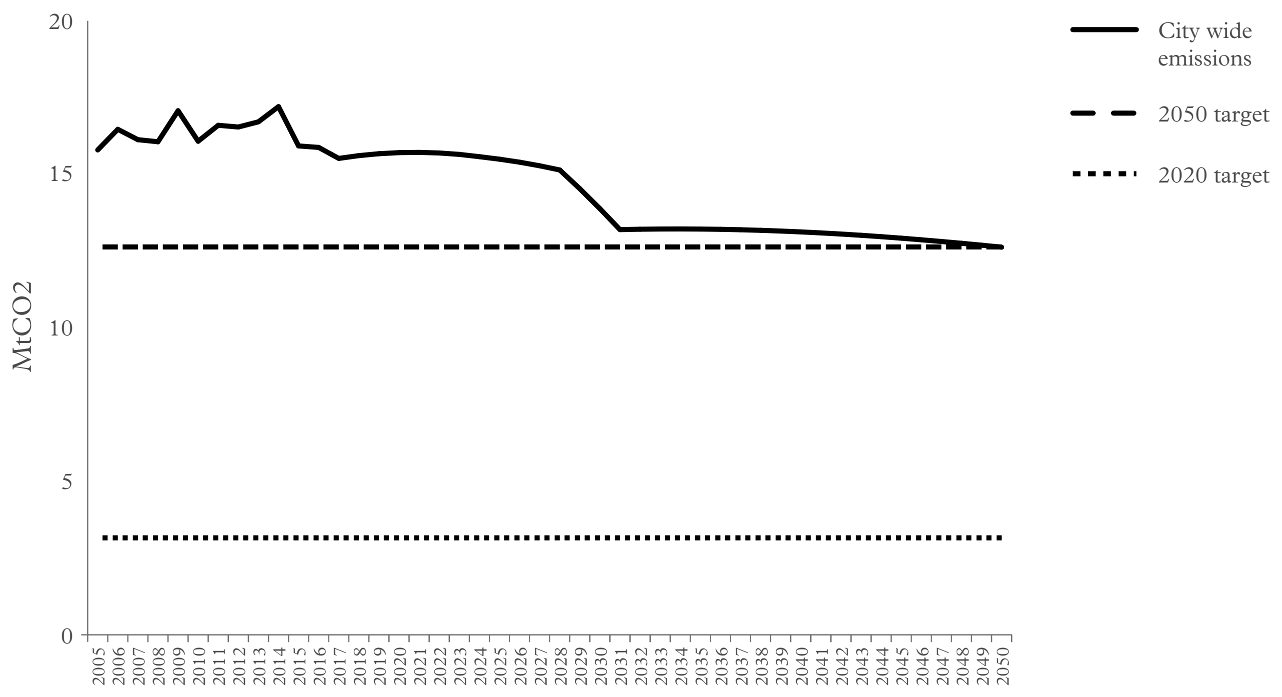
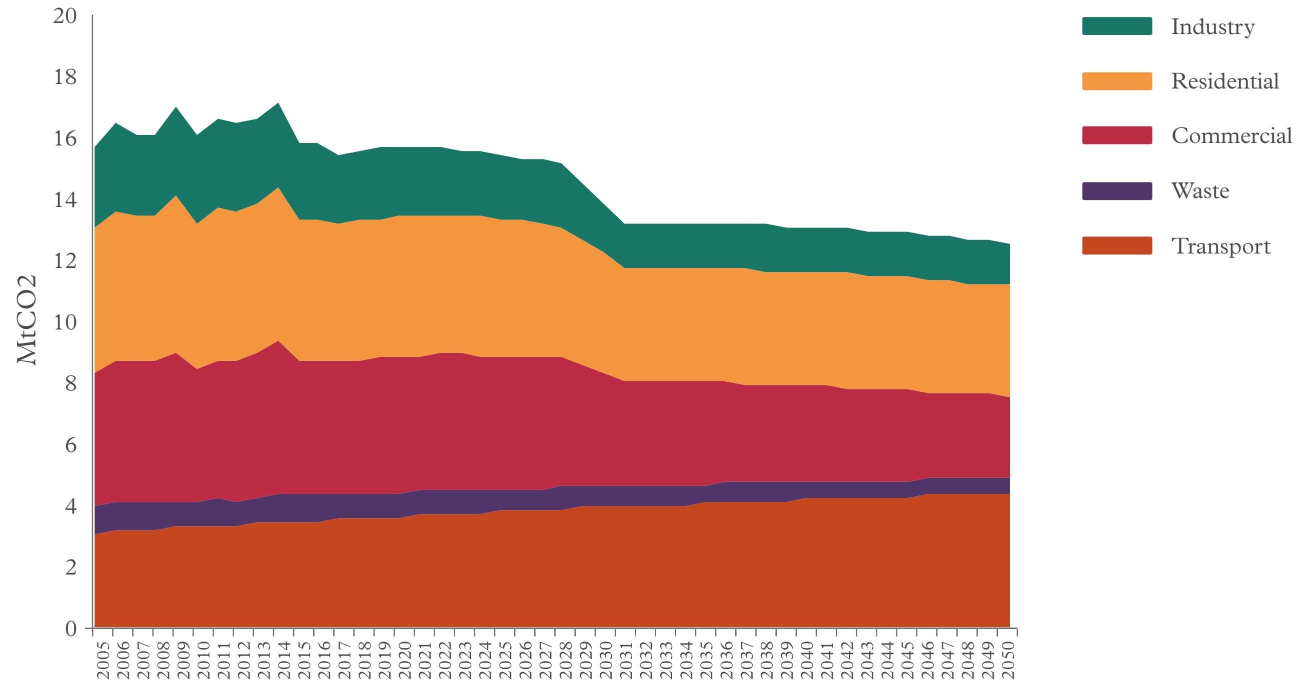


Figure 5: Source of emissions by sector, 2005-2050



The Potential for Reducing Carbon Emissions

As summarised in Figure 6, aggregated results indicate that Calgary could substantially reduce its emissions between 2017 and 2050. Specifically, we find that Calgary could reduce its emissions by:

— 41% through cost effective investments that would pay for themselves (8% real discount rate) and provide further profits over their lifetime. This would require cumulative investment of $12.4 billion and generating average savings of up to $4.2 billion per year. Using net present values, the investment is paid back in 3 years.

—70% through cost neutral investments that could be paid for at no net cost to the city's economy if the benefits from cost effective measures were captured and re-invested in further low carbon measures. This would require cumulative investment of $100.4 billion, generating savings of up to $5.7 billion per year. Using net present values, the investment is paid back in 17 years with savings continuing over the lifetime of the measures still in place.

—77% with the exploitation of all of the realistic potential of the different measures considered. This would require cumulative investment of $177 billion, generating savings of up up to $7.2 billion per year. Using net present values, the investment is paid back in 24 years with savings continuing over the lifetime of the measures still in place.

Figure 6: Calgary' emissions under the baseline and carbon reduction scenarios

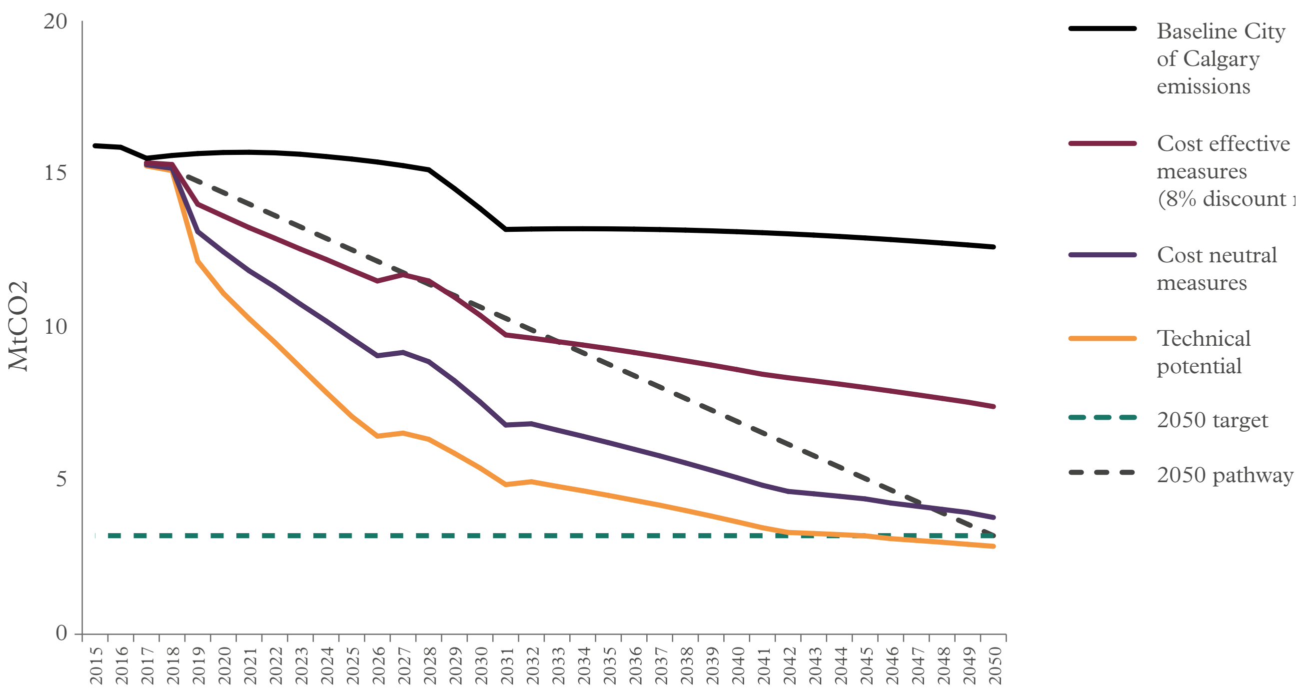


Table 8 illustrates the cost per tonne of emissions saved for each of these scenarios. The cost effective scenario has a negative value, indicating that every tonne of carbon saved leads to a net economic return of approximately $68. On a per tonne basis the cost neutral and technical potential scenarios are progressively more expensive, demonstrating the higher cost of reducing higher levels of emissions. These figures align with other research conducted in Canada as well as globally on the cost of reducing carbon emissions. A relatively small set of measures are generally found to produce net economic returns for emissions saved at a net negative cost of $50-$100 per tonne, while at progressively higher levels of mitigation costs rise quickly.

It is important to note that these figures do not take into account the levels of carbon that are embedded in all of the goods and services consumed in Calgary – the 'Scope 3' emissions. Research has shown that when these are taken into account in wealthy regions of the world, carbon emissions are substantially higher and may be rising rather than falling.

Impact on Energy Bills

Calgary currently spends $2.6 billion on energy each year, or 3% of all money earned in the city. By 2030 this could rise to $6 billion and 4% of all money earned in the city through expected increases in energy price and the expansion of economic activity. However, reducing carbon emissions directly translates into reduced energy use and energy bills across the city[11].

—With investment in cost effective measures, the 2030 annual energy bill could be cut by $1.7 billion (29%), or $1100 per person per year.

—With investment in cost neutral measures, the 2030 energy bill could be cut by $2.55 billion (42%), or $1600 per person per year.

—With investment to exploit all of the realistic potential the 2030 energy bill could be cut by $3.1 billion (54%), or $2100 per person per year.

Residents and businesses within the city of Calgary could therefore significantly enhance their energy security through investments in energy efficiency and low carbon options.

Table 8: Cost per tonne of emissions scenarios

Scenario	Cost per tonne ($/tonne CO2)
Cost effective	-$67
Cost neutral	$51
Technical potential	$111

The Most Cost and Carbon Effective Options

High level results from the city of Calgary show strong similarities with a wide literature on low carbon investments in cities,. A range of investments, including ones in each of the residential, commercial, industrial, transportation and waste sectors, can reduce emissions while providing returns to investors. However, the specific options available to Calgary are unique to the urban context.

Calgary has a relatively low density compared with other major cities in Canada, approximately 1500 people per square kilometre compared with 4300 people per square km in Toronto, 4700 in Montreal and 5500 in Vancouver. As a consequence, public transportation is both less developed – leading to a higher reliance on private vehicles – and may have less potential for expansion (due to the fact that lower density areas produce lower ridership). In addition, lower density leads to relatively larger homes, and a relatively larger proportion of the population living in single family homes, as opposed to townhouses or apartments. Transportation and housing thus emerge as two areas that are a unique challenge, and opportunity, for low carbon actions in Calgary.

[11] It is important to note, not all actions that reduce GHG emissions reduce energy use. In fact, in some cases energy use can be increased. However, across the actions assessed in this report reducing GHG emissions leads to energy savings.

As summarised in Table 9, we find that the most carbon effective opportunities can be found in the residential sector and especially in the existing housing stock, where a range of interventions – from relatively 'shallow' and non-intrusive measures to 'deeper' and more ambitious measures - can save substantial emissions. Particular carbon effective opportunities are also available in the transportation sector where alternative fuels and electric vehicles present two major opportunities for emissions reductions.As summarised in Table 10, a number of options show significant potential for reducing emissions while generating returns for investors. Cost-effective options in the residential and transportation sectors can also be found in the carbon-effective list, specifically, hybrid and electric cars, and low level retrofits.

It is important to note, the party that bears the cost of investment may not be the same party that benefits from energy savings. Innovative benefit sharing or cost-recovery mechanisms may therefore be needed if these investment opportunities are to be realised. Further, the way these options are pursued (e.g. the policies adopted to support invesment) can affect the economic returns. This is particularly the case for options such as shallow retrofits in existing and new residential buildings, or for the adoption of a mid performance-based standard for new town-homes and for increased parking levies, where principal-agent challenges may need to be overcome.

Table 9: 10 most carbon effective opportunities

Rank	Sector	Subsector	Intervention (s)	Carbon savings (Mt CO2 over lifetime)
1	Residential	Single family homes (existing)	Zero Energy building, High Performance-Based Standard, Upgrade to mid Performance-Based Standard, Upgrade to code	11-86Mt
2	Transport	Private vehicles (light, medium and heavy)	Electric vehicles	7-65Mt
3	Residential	Single family homes (new)	Zero Energy building, high Performance-Based Standard, Upgrade to mid Performance-Based Standard, Code plus efficient lights and appliances	22-57Mt
4	Commercial	Retail (new)	New 1 (AEDG 30), New 2 (AEDG 50)	16-26Mt
5	Transport		Biofuel (B20)	17Mt
6	Waste		Energy from waste (CHP and electricity), incineration, landfill gas utilization	13-15Mt
7	Land-use	Buildings and transportation	MDP and MDP+	7-12Mt
8	Transport		Increased parking levies	12Mt
9	Transport		Reduced car ownership	8Mt
10	Residential	Townhouses (existing)	Zero Energy building, high Performance-Based Standard, Upgrade to mid Performance-Based Standard, Code plus efficient lights and appliances	2-22Mt

Table 10: The top 10 cost effective actions[12]

Rank	Sector	Subsector	Intervention (s)	Carbon savings (Mt CO2 over lifetime)
1	Land-use		MDP and MDP+	($300-325)
2	Transport	Private vehicles	Increasing parking levies	($270)
3	Transport	Goods transport	Electric goods vehicles (light, medium and heavy)	($225-245)
4	Transport	Private vehicles	Hybrid private vehicles	($70) to ($140)
5	Transport	Private vehicles	Electric private vehicles	($50-110)
6	Residential	Existing apartments, townhouses and single family homes	Retrofit 1: Efficient lights and appliances	($60-80)
7	Commercial	Retail/Offices/Warehouses	Shallow retrofit	($40-60)
8	Residential	New apartments, townhomes, and single family homes	Code + Efficient lights and appliances	($30) to ($40)
9	Commercial	Existing retail	Moderate-Deep Retrofit	($20)
10	Commercial	New offices	AEDG 30%-50%	($10-20)

[12] Actions which save less than 100kt CO2 over the period to 2050 are excluded. Where multiple similar actions were found, actions are grouped and a range in cost effectiveness is shown.

Impacts on Employment

Investments in low carbon actions in Calgary could generate substantial employment opportunites. Table 11 presents these impacts by sector and scenario in thousands of job-years: The number of full-time jobs for one person for one year generated from investment. Results show: More than 70,000 job-years could be generated by investment in cost-effective low carbon actions.

-Nearly 860,000 job-years could be generated by investing in cost neutral options.

-Almost 2 million job-years could be generated by investing in all of the options at their maximum potential in this report.

The most substantial job impacts are generated by retrofits in the residential and commercial sectors. Research finds that for every million invested 13 and 10 net new jobs are created in each respective sector.

However, it needs to be strongly emphasized that constraints on the number of skilled workers could be a major limitation on any large retrofit program, reducing the number of jobs that could be created. Under the cost neutral and technical potential scenario large impacts on employment are also seen in the transportation sector, where substantial investments in expanding the capacity and scale of the public transportation network would need to be undertaken.

These figures should be treated with a high degree caution. While a substantial body of research in North America and Europe establish that higher building standards and retrofits, among other actions, generate increased employment – even after considering the jobs lost in other industries from diverted investment – the impacts of many types of investments are uncertain, especially for the cost neutral and technical potential scenarios. Electric vehicles and land-use change are assumed to have a zero net impact on employment in this analysis. The impacts of investments are highly dependant on economic conditions: If unemployment is relatively high the potential for net job creation is relatively larger. However, as the economy reaches full employment the number of net jobs created may be smaller. The net impacts of investments will also be affected by technical change, which typically reduces employment impacts.

Table 11: Thousands of job-years created by investment in each sector

	Transportation	Industry (s)	Waste	Residential	Commercial	Distributed energy	Total
Cost effective investments	0	1	-3	50	23	0	71
Cost neutral investments	291	4	3	427	69	67	860
Technical potential investments	664	7	0	1124	69	67	1931

Wider Social, Environmental and Economic Impacts:

Results from a Multi-Criteria Analysis

=The presence of an economic or carbon case for investment, while necessary in some cases, is not sufficient for action. Indeed, city-level investments in the residential, commercial, industrial, transportation and waste sectors are typically made with range of other criteria as the primary motivation for action. For example, improving public health is an important consideration in the waste sector and improving mobility is a key consideration in the transportation sector.

In order to capture the public's perception of the actions investigated by this analysis, an online survey was completed by 262 participants. The results of this survey will not directly influence which low carbon actions the City includes in their low carbon plan. Rather, the results will be used to inform a longterm process, involving further engagement with stakeholders, to understand the most effective and desireable programs and policies.

It should be emphasised, the subset of the Calgary population capture by this survey was not representative. Respondents, on average, were relatively older, and better educated than average, and males were over-represented. Further, it should be noted that results reflect public opinion on the desirability of different low carbon measures without extensive information being provided, for example on specific policy approaches for implementation, the modelled carbon and economic results or their expected impact. None-the-less, these results provide an indication of where Calgarian's see potential for positive and negative social, environmental, and economic impacts from the measures investigated, providing information that can be used by the City of Calgary as they move towards developing a low carbon plan.

The seven criteria evaluated are:

- Economic development and impact
- Environmental co-benefits
- Accessibility and equity
- Human health and well-being
- Capacity for implementation
- Political acceptability
- Public acceptability

Below, scores are presented on the desirability of different measures when assessed against each of seven criteria. Scores greater than zero indicated that respondents on average foresee a net positive social/economic/environmental impact from a measure. Zero indicates that respondents anticipated a net neutral impact and negative scores indicate a negative impact. For each criterion, the highest possible score is 10 while the lowest is -10.

a) Accessibility and Equity

The 'accessibility and equity' criterion assesses the extent to which respondents felt that costs and benefits will be distributed fairly amongst Calgarians. As set out in Table 12, respondents indicated that waste prevention measures and investments in public transit expansion would have the most equitable impact but that deep retrofits in the residential sector and increasing parking levies would have the most inequitable impacts.

Table 12: Top and bottom 3 MCA result for 'Accessibility and equity'

	Sector	Measure	Score
Top 3	Waste	Prevention (5-10% target)	3.4
	Transportation	Free transit	3.4
	Transportation	Transit wait times reduced (25% - 50% target)	3.1
Bottom 3	Residential	New Very High – addition of solar PV array	-2.8
	Transportation	Increasing parking levies	-3.2
	Residential	Retrofit Very High – Addition of solar PV array	-3.6

b) Capacity for Implementation

The 'capacity for implementation' criterion provides an indication of the extent to which respondents perceived that each measure could be practically delivered. As set out in Table 13, shallow retrofits were perceived as being less challenging to implement while a set of measures in the transportation sector were seen to be relatively more challenging. Comments noted that these measures would potentially require provincial/federal support and technological advancements to be implemented.

Table 13: Top and bottom 3 MCA results for 'Capacity for implementation'

	Sector	Measure	Score
Top 3	Residential	New Low – Upgrade lighting and appliances	5.9
	Residential	Retrofit Low – Upgrade to current building code	5.3
	Commercial	Retrofit 1 – Shallow Retrofit	5.3
Bottom 3	Transportation	Biofuel (B20)	-1.3
	Transportation	Electric vehicles (5-50% target by 2030)	-1.3
	Transportation	Reduced car ownership (20-40% target)	-2.2

c) Potential to contribute to economic development

The 'economic development' criterion assesses the extent to which respondents see potential for a measure to generate wider economic benefits for the. As set out in Table 14, respondents saw potential for positive wider economic impacts from deep retrofits and solar PV expansion, and potential for negative wider economic impacts from pursuing policy options around several transportation measures.

Table 14: Top and bottom 3 MCA results for 'Economic development'

	Sector	Measure	Score
Top 3	Residential	Retrofit Very High – Addition of solar PV array	3.3
	Distributed energy	Solar PV	3.1
	Residential	New Very High – addition of solar PV array	3.0
Bottom 3	Transportation	Carpooling	-2.9
	Transportation	Reduced car ownership (20-40% target)	-2.9
	Transportation	Increasing parking levies	-3.8

d) Potential for environmental co-benefits

The 'environmental co-benefits' criterion assesses the extent to which respondents saw potential for measures to affect the environment beyond reductions in carbon emissions. As is shown in Table 15, waste prevention was seen as having the largest potential for positive environmental impact, while waste incineration was seen as potentially having the largest potential for negative environmental impact

Table 15: Top and bottom 3 MCA results for 'Environmental co-benefits'

	Sector	Measure	Score
Top 3	Waste	Prevention (5-10% target)	5.3
	Transportation	Increased cycling and walking to work	4.0
	Distributed energy	Solar PV	2.8
Bottom 3	Transportation	Increasing parking levies	-1.3
	Waste	Landfill gas flaring	-1.7
	Waste	Incineration	-3.5

e) Impacts on human health and well-being

The 'Human health and wellbeing' criterion assesses the extent to which respondents see measures as improving the lives of Calgarians. As set out in Table 16, increased cycling and waste prevention were seen as two measures with the potential to significantly positively influence the wellbeing of Calgarian's while residential retrofit and waste incineration were seen as the measures with the potential for negative influence.

Table 16: Top and bottom 3 MCA results for 'Human health and wellbeing'

	Sector	Measure	Score
Top 3	Transportation	Increased cycling and walking to work	5.6
	Waste	Prevention (5-10% target)	5.0
	Transportation	Free transit	2.9
Bottom 3	Residential	Retrofit High – Upgrade to optimal insulation	-0.2
	Residential	Retrofit Very High – Addition of solar PV array	-1.0
	Waste	Incineration	-4.0

f) Political acceptability

The 'political acceptability' criterion considers the extent to which respondents saw potential for political support for or opposition to different measures. As is shown in Table 17, Solar PV and shallow retrofits were seen to have greatest potential for polictical support, while waste incineration, free transit and deep retrofits were seen to have more potential for political opposition.

Table 17: Top and bottom 3 MCA result for 'Political acceptability'

	Sector	Measure	Score
Top 3	Distributed energy	Solar PV	2.8
	Commercial	Retrofit 1 – Shallow Retrofit	2.7
	Residential	New Low – Upgrade lighting and appliances	2.6
Bottom 3	Residential	Retrofit Very High – Addition of solar PV array	-1.0
	Transportation	Free transit	-1.5
	Waste	Incineration	-2.3

g) Public acceptability

The 'public acceptability' criterion assesses the extent respondents saw potential for public support for or opposition to different actions. As is presented in Table 18, shallow retrofits were seen to have the most potential for public support, while deep retrofits, increased parking levies and incineration were seen to potential for public opposition.

Table 18: Top and bottom 3 MCA results for 'Public acceptability'

	Sector	Measure	Score
Top 3	Residential	New Low – Upgrade lighting and appliances	3.4
	Commercial	Retrofit 1 – Shallow Retrofit	3.2
	Residential	Retrofit Low – Upgrade to current building code	3.1
Bottom 3	Residential	Retrofit Very High – Addition of solar PV array	-2.7
	Transportation	Increasing parking levies	-3.1
	Waste	Incineration	-3.1

h) Aggregated scores

Aggregated scores across the seven criteria for the top 10 measures are presented in Table 14 and for the bottom 10 measures in Table 19. Scores greater than zero indicate that respondents on average foresee a net positive social, economic and environmental impact from a measure, a score of zero indicates respondents anticipated a net neutral impact and negative scores indicate a net negative impact. The highest possible score is 70 while the lowest is -70.

Table 19: 10 measures that received the highest scores across all criteria

Sector	Measure	Score
Waste	Prevention (5-10% target)	24.5
Distributed energy	Solar PV	17.4
Residential	New Low – Upgrade lighting and appliances	15.5
Waste	Land-fill gas utilization	15.3
Residential	Retrofit Low – Upgrade to current building code	13.6
Commercial	Retrofit 1 – Shallow Retrofit	14.3
Transportation	Increased cycling and walking to work	13.0
Residential	New Medium – Upgrade to mid-optimal insolation	12.3
Commercial	New 1 - 'Shallow' Standard For Buildings	12.4

Results show that respondents saw the potential for positive impacts across a range of actions in different sectors. Notably, the actions which received the highest scores tended to be relatively less invasive and lower cost compared with other measures in each sector. While solar PV showed up as having one of the highest overall scores, a more specific scenario involving solar PV showed a net negative impression of this measure. This suggests that the specific approach to implementation can be very important in shaping public perceptions of different low carbon options.

Measures with a negative score indicate that survey respondents anticipated a net negative impact from these measures across the different social/environment and economic criteria considered. Approximately 1 in 5 of the measures assessed received a negative score. As can be seen in Table 3, measures in the waste and transportation sectors are disproportionately represented in this category. This table also show that more expensive and invasive measures received significantly lower scores. This suggests that respondents generally preferred cheaper options that could be more readily assimilated into existing structures.

Table 20: 10 measure that received the lowest scores across all criteria

Sector	Measure	Score
Waste	Incineration	-12.4
Transportation	Increasing parking levies	-11.1
Transportation	Reduced car ownership (20-40% target)	-8.0
Transportation	Biofuel (B20)	-7.1
Waste	Landfill gas flaring	-5.1
Transportation	Hybrid vehicles (5-50% target by 2030)	-1.0
Residential	Retrofit Very High – Addition of solar PV array	-0.9
Transportation	Electric vehicles (5-50% target by 2030)	-0.9
Distributed energy	Distributed Wind Compressed natural gas heavy vehicle transportation	0.3
Transportation		0.4

Sensitivity Analysis

Energy prices and the carbon intensity of the electricity grid are two key variables affecting the economic case for low carbon actions, and the pathway of future emissions. Figure 7 illustrates how each scenario would change if each of these variables was 50% higher, or 50% lower, in 2050. We refer to a case with relatively higher energy prices and higher electricity grid decarbonisation as the 'optimistic case', and lower energy prices and lower decarbonisation of the electricity grid as the 'pessimistic case'. A number of findings are important t note.

First, altering assumptions around these variables can lead to very large changes in emissions. Indeed, in the 'pessimistic case' emissions under the cost effective scenario would rise over the period to 2050, and would be higher than the optimistic baseline scenario – as seen by the overlap between the green and grey shaded areas.

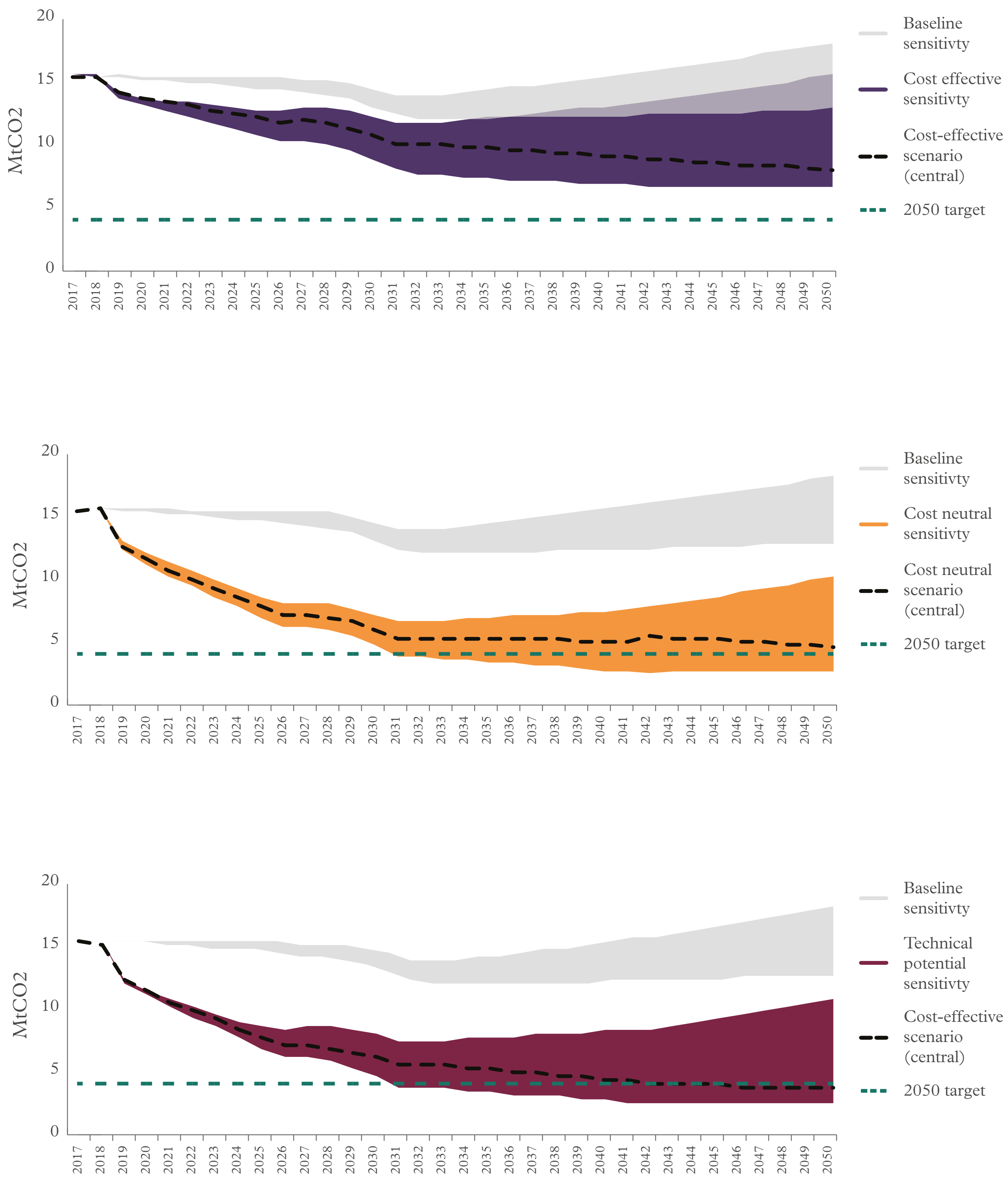
Second, changes in the carbon intensity of the electricity grid will have a substantial impact on future emissions from the city. As seen in the baseline sensitivity, changes in the electricity grid could lead to a difference in emissions of 5.5Mt CO2 in 2050, an amount that is larger than the total carbon savings from cost effective measures under the central scenario in 2050 (5.2 MtCO2). This emphasizes the need for actions in Calgary to be complemented by actions at the Provincial and National levels.

Third, in the 'optimistic case' meeting Calgary's 2050 carbon targets is low cost, or potentially zero (net) cost. To identify this it is important to remember the definition of each scenario. The cost effective scenario includes the set of options that make investors the most money. Since higher energy prices improve the economic case of nearly all measures, the level of ambition within the scenario changes very little with changes in energy prices. For example, in the residential sector relatively shallow retrofits are the most economic action at both relatively low and high energy prices and since homes can only be retrofit one time in this analysis, each homeowner decides to do a shallow retrofit.

The cost neutral scenario, by contrast, comprises the set of measures that generate the largest carbon savings with the scenario as a whole maintaining an indicated rate of return equal to or greater than zero. Under the 'optimistic case' and the cost neutral scenario Calgary could significantly exceed its 2050 target.

Finally, while the sensitivity analysis illustrates the large differences between scenarios of energy prices and grid intensities, the conclusions within any given scenario are similar to those from the headline scenario. Irrespective of which 'case' becomes reality, a large set of low carbon actions across the economy could generate economic returns and move the city away from baseline emissions.

Figure 7: Sensitivity analysis around scenario results. Shaded regions are the variations in the projected trajectories when moving from low energy prices and limited grid decarbonisation to high energy prices and rapid grid decarbonisation



Chapter 4.0
Sector Specific Results

4.1 The Residential Sector

In the residential sector, the potential for energy savings and low carbon investments in three types of buildings and residences was assessed: single family detached homes, attached homes and townhouses, and apartment units. As of 2016, 58% of dwellings in Calgary were single family homes, the highest proportion among the largest 5 cities in Canada, and slightly higher than the Canadian average (including both urban and rural areas), of 55%. Emissions from different types of residence vary significantly, largely due to the average size of a unit of each type, with single family detached homes bearing the highest emissions and utility costs and apartment units the lowest. This provides a larger opportunity for emissions reductions and cost savings in single family detached homes and also an opportunity for savings through a shift from single family homes to more urban settings in townhouses and apartments. The latter is explored further in the land-use section.

Calgary is a city with significant sprawl and a number of new residential developments are being built within and beyond the borders of the city. Due to higher housing costs in the downtown and near downtown areas, new home buyers are often attracted to the less expensive single family home developments on the outskirts of the city. This provides a unique challenge to residential emissions as the impacts are shifted further towards the transportation sector as the city expands. At the same time, the importance of building energy efficient new homes remains of high importance, but this must be balanced with real estate cost for new home owners.

The Opportunity for Carbon Reduction: Investments and Returns

Our analysis shows that investments in the residential sector could substantially impact energy use, energy bills and carbon emissions. More specifically, we find that by 2050 carbon emissions could be reduced by:

-36% through cost effective investments that would pay for themselves (at an 8% interest rate), over their lifetime. This would require investment of $3.8 billion, generate average annual energy savings of $930 million, and payback the original investment in 4 years.

-80% through cost neutral investments that could be made at no net cost to the city's economy if the economic returns from cost effective investments were reinvested in further actions. This would require investment of $32.8 billion, generate average annual energy savings of $1.4 billion and payback the original investment in 23 years.

-100% with the exploitation of the technical potential of current opportunities to reduce carbon emissions. This would require investment of $87 billion, generate average annual energy savings of $2.4 billion and payback the original investment in 36 years.

Employment impact

Low carbon investments cannot be realised without skilled tradespeople, engineering know-how and support from a variety of industries across the city.

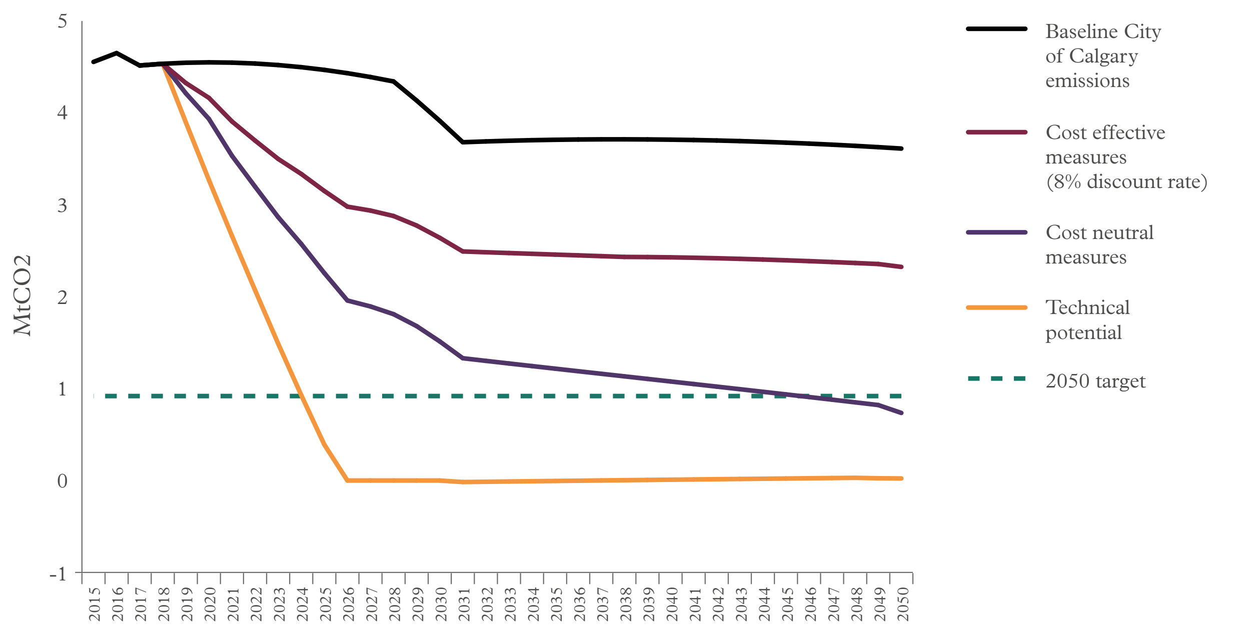
-Investments in cost effective measures in the residential sector could generate nearly 50,000 years of employment. Over the period to 2050 this could mean steady employment for 1000 Calgarians.

-Investments in cost neutral measures in the residential sector could generate more than 400,000 years of employment. Over the period to 2050 this could mean steady employment for more than 8000 Calgarians.

-Investment in all possible measures in the residential sector could generate more than 1 million years of employment. Over the period to 2050 this could mean steady employment for more than 20,000 Calgarians.

These figures should be treated with caution and interpreted as indicative of the relative scale of potential impacts on employment under different scenarios. Particularily in the cost neutral and technical potential scenarios, constraints on the number of available skilled workers could dramatically limit employment impacts.

Figure 8: Baseline and scenario emissions for the residential sector



Results from the MCA

Results from a multi-criteria analysis survey provide an indication of Calgarian's perceptions of some of the wider potential impacts of the different measures under consideration

Results show that respondents see potential for significant net social, economic and environmental benefits from the subset of relatively 'shallower' interventions. These include shallow retrofits of existing buildings and small increases in the existing standard. These are the actions that are the least invasive and would require the least investment. Respondents saw net, but relatively smaller benefits from more aggressive interventions, with the exception of very high retrofits with the addition of a solar array where the net benefits were perceived to be marginally negative. The highest criteria scores were for the 'capacity for implementation' of shallow retrofits. The lowest scores were for the 'political acceptability' of deep retrofits.

Discussion

Cost effective actions in the residential sector can substantially impact carbon emissions while generating net economic returns for investors. Relatively shallower interventions, such as improvements to appliances and lighting, show strong carbon and economic cases for action. This suggests that policy interventions built around these actions may show the strongest case for implementation. At the same time, meeting the City's carbon targets by 2050 will require more aggressive actions. Working closely with stakeholders in the residential sector will therefore be critical in order to find means of improving building efficiency without placing unmanageable costs on buildings or homeowners.

An area of particular challenge, and opportunity, lies in the existing building stock. Existing buildings, constructed under previous building codes and in a variety of models and types, present unique challenges, and in some cases buildings may need to be entirely replaced. At the same time, relatively lower energy efficiency (relative to buildings built today), and an aggressive retrofit scenario in this analysis[13], reveal that retrofitting buildings may present a larger opportunity for carbon and energy expenditure savings. The challenge for the City, and urban stakeholders, will be to develop policies targeting the households where the opportunity for intervention is greatest.

Table 21: MCA results for the residential sector

Measure	Score
New Low – Upgrade lighting and appliances	15.5
Retrofit Low – Upgrade to current building code	13.6
New Medium – Upgrade to mid-optimal insulation	12.3
New High – Upgrade to optimal insulation	9.9
Retrofit Medium – Upgrade to mid-optimal insulation	8.9
Retrofit High – Upgrade to optimal insulation	5.5
New Very High – addition of solar PV array	2.8
Retrofit Very High – Addition of solar PV array	-0.9

[13] In the retrofit scenario all buildings of a specific type are retrofit to a given standard over the period between 2019 and 2026. New building standards affect new buildings built after 2019. Since the electricity grid is significantly decarbonising over the period between 2019 and 2030 and the entirely existing building stock is retrofit over this period, retrofits of buildings save larger amounts of carbon than new building standards.

League Tables of the Most Cost and Carbon Effective Measures

Table 22: Most cost effective measures, residential sector

Housing type	Intervention	Description	$/tonne
single family house	Retrofit 1	Efficient lights and appliances	-$84
Apartment	Retrofit 1	Efficient lights and appliances	-$70
Townhouse	Retrofit 1	Efficient lights and appliances	-$60
single family house	New 1	Code + Efficient lights and appliances	-$41
Townhouse	Retrofit 2	Upgrade to code	-$39
Apartment	New 1	Code + Efficient lights and appliances	-$39
Townhouse	New 1	Code + Efficient lights and appliances	-$32
single family house	Retrofit 2	Upgrade to code	-$31
Townhouse	Retrofit 4	Upgrade to mid performance-base	-$31
Apartment	Retrofit 2	Upgrade to code	-$22
Apartment	Retrofit 4	Upgrade to mid performance-base	$7
Townhouse	New 3	Upgrade to mid performance-base	$15
Apartment	New 6	Net Zero Energy Building	$47
single family house	New 4	Upgrade to high performance base	$50
single family house	New 3	Upgrade to mid performance-base	$50
Townhouse	New 4	Upgrade to high performance base	$55
Apartment	New 5	Upgrade to high performance base + Heat pump	$60
single family house	New 6	Net Zero Energy Building	$63
Townhouse	New 6	Net Zero Energy Building	$64
Apartment	New 4	Upgrade to high performance base	$67
single family house	New 5	Upgrade to high performance base + Heat pump	$69
Townhouse	New 5	Upgrade to high performance base + Heat pump	$72
Townhouse	Retrofit 3	Upgrade to code + Heat pump	$126
single family house	Retrofit 4	Upgrade to mid performance-base	$132

single family house	Retrofit 3	Upgrade to code + Heat pump	$171
single family house	New 2	Heat pump	$191
Apartment	Retrofit 5	Upgrade to high performance base	$195
Apartment	Retrofit 6	Upgrade to high performance base + Heat pump	$200
Townhouse	Retrofit 5	Upgrade to high performance base	$207
Apartment	Retrofit 7	Net Zero Energy Building	$209
Townhouse	Retrofit 6	Upgrade to high performance base + Heat pump	$220
Townhouse	Retrofit 7	Net Zero Energy Building	$223
single family house	Retrofit 5	Upgrade to high performance-base	$238
Townhouse	New 2	Heat pump	$246
single family house	Retrofit 7	Net Zero Energy Building	$254
single family house	Retrofit 6	Upgrade to high performance base + Heat pump	$256
Apartment	New 3	Upgrade to mid performance-base	$259
Apartment	Retrofit 3	Upgrade to code + Heat pump	$685
Apartment	New 2	Heat pump	$4,702

Table 23: Most carbon effective measures, residential sector

Housing type	Intervention	Description	Total carbon savings (lifetime, Mt)
single family house	Retrofit 7	Net Zero Energy Building	86
single family house	Retrofit 6	Upgrade to high performance base + Heat pump	71
single family house	Retrofit 5	Upgrade to high performance-base	67
single family house	New 6	Net Zero Energy Building	57
single family house	New 5	Upgrade to high performance base + Heat pump	49
single family house	Retrofit 4	Upgrade to mid performance-base	44
single family house	New 4	Upgrade to high performance base	43
single family house	Retrofit 3	Upgrade to code + Heat pump	32
single family house	Retrofit 2	Upgrade to code	24
Townhouse	Retrofit 7	Net Zero Energy Building	22
single family house	New 1	Code + Efficient lights and appliances	22
single family house	New 3	Upgrade to mid performance-base	21
Apartment	New 6	Net Zero Energy Building	20
Townhouse	Retrofit 6	Upgrade to high performance base + Heat pump	19
Apartment	New 5	Upgrade to high performance base + Heat pump	18
single family house	New 2	Heat pump	18
Townhouse	Retrofit 5	Upgrade to high performance base	17
Apartment	Retrofit 7	Net Zero Energy Building	16
Townhouse	New 6	Net Zero Energy Building	16
Apartment	New 4	Upgrade to high performance base	14
Apartment	Retrofit 6	Upgrade to high performance base + Heat pump	14
Townhouse	New 5	Upgrade to high performance base + Heat pump	13
Apartment	Retrofit 5	Upgrade to high performance base	12

Townhouse	Retrofit 4	Upgrade to mid performance-base	11
Townhouse	New 4	Upgrade to high performance base	11
single family house	Retrofit 1	Efficient lights and appliances	11
Townhouse	Retrofit 3	Upgrade to code + Heat pump	10
Townhouse	New 1	Code + Efficient lights and appliances	10
Apartment	New 1	Code + Efficient lights and appliances	9
Townhouse	Retrofit 2	Upgrade to code	8
Apartment	Retrofit 4	Upgrade to mid performance-base	6
Apartment	Retrofit 2	Upgrade to code	5
Townhouse	New 2	Heat pump	5
Townhouse	New 3	Upgrade to mid performance-base	4
Apartment	Retrofit 3	Upgrade to code + Heat pump	3
Townhouse	Retrofit 1	Efficient lights and appliances	2
Apartment	Retrofit 1	Efficient lights and appliances	2
Apartment	New 3	Upgrade to mid performance-base	1
Apartment	New 2	Heat pump	0

4.2 The Commercial Sector

In the commercial sector, three types of buildings were assessed: office spaces, warehouses, and retail spaces. These commercial spaces in the city contribute 4.4 Mt of GHG emissions per year and consume energy at a cost of $420 million per year, equating to nearly 28% of Calgary's total energy consumption and carbon emissions. Office spaces and warehouses each hold 40% of the overall space in the commercial sector, with retail taking up the remaining 20% of commercial space in the city. Despite the lower overall space, retail makes up roughly 33% of the electricity consumption and emissions, with warehouses contributing 27% and offices 40%. Due to the nature of their operation, the opportunities available for cost savings and emissions reductions vary between the three building types. Warehouses, with the lowest emissions of the group, have the least room for improvement but may still find it easier to implement many of the measures. Retail spaces, on the other hand, are subject to the consumer market and must maintain an atmosphere and ambiance that best supports the activities within them. This makes it more of a challenge to implement emissions and cost savings measures, despite the extra potential in the retail space. With these restrictions in mind, there are a number of cost effective measures that can be implemented in each of the spaces to reduce emissions.

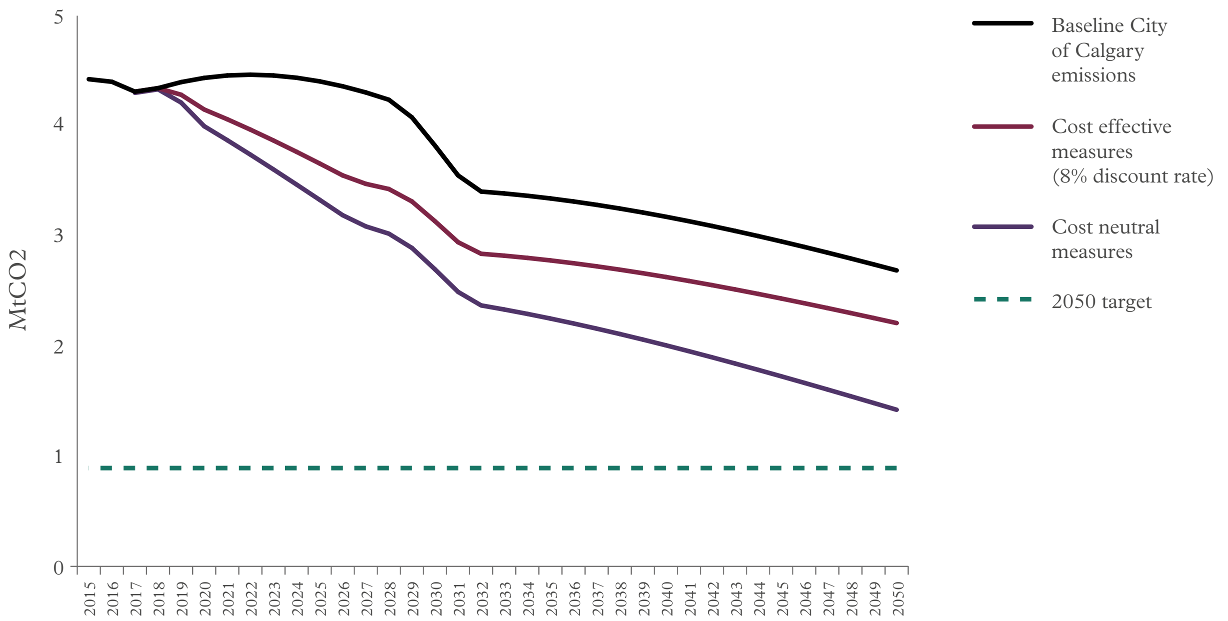
The Opportunity for Carbon Reduction: Investments and Returns

Investments in low carbon options in Calgary's commercial buildings sector could substantially impact on its energy use and carbon emissions. We find that by 2050 carbon emissions could be reduced by:

-18% through cost effective investments that would pay for themselves (at an 8% interest rate), over their lifetime. This would require investment of $2.3 billion, generate average annual energy savings of nearly $400 million, and payback the original investment in 6 years.

-47% through cost neutral investments that could be made at no net cost to the city's economy if the economic returns from cost effective investments were reinvested in further actions. This would require investment of $6.9 billion, generate average annual energy savings of approximately $500 million and payback the original investment in 13 years.

Figure 9: Baseline and scenario emissions for the commercial sector



Employment impact

Low carbon investments cannot be realised without skilled tradespeople, engineering know-how and support from a variety of industries across the city.

-Investments in cost effective measures in the commercial sector could generate more than 20,000 years of employment. Over the period to 2050 this could mean steady employment for nearly 500 Calgarians.

-Investments in cost neutral measures in the commercial sector sector could generate nearly 70,000 years of employment. Over the period to 2050 this could mean steady employment for more than 1000 Calgarians.

These figures should be treated with caution and interpreted as indicative of the relative scale of potential impacts on employment under different scenarios. Particularily in the cost neutral scenario, constraints on the number of available skilled workers could dramatically limit employment impacts.

Results from the MCA

Results from the multi-criteria analysis provide an indication of Calgarian's perception of some of the wider potential impacts of the range of measures evaluated.

Results show that respondents perceive there to be net potential social, environmental and economic benefits from all actions in the commercial sector with the largest potential benefits from relatively 'shallower' interventions. This result is in line with the residential sector where similar interventions were presented. Relatively shallower retrofits received significantly higher scores for the criteria 'capacity for implementation' and 'political acceptability' while deeper retrofits received marginally higher scores for 'environmental co-benefits' and 'human health and well-being'.

Discussion

Similar to the residential sector, results from the commercial sector show that relatively "shallower" interventions, such as improvements to appliances and upgrades to code, show strong carbon, economic cases for action. At the same time, the most ambitious retrofit and new building standards have an even larger impact on emissions. The economic case for these more aggressive actions is more challenging - cost effective actions payback in 6 years while cost neutral actions would require more than a decade – however a net economic return could be achieved from these actions if investors were willing to receive a lower return on their investment (6% or 7% rather than 8%), or if actions could target the specific buildings or developments with the largest opportunities.

Table 24: MCA results for the commercial sector

Measure	Score	% of maximum possible score
Retrofit 1 – Shallow Retrofit	14.3	20%
New 1 - 'Shallow' Standard For Buildings	12.4	18%
Retrofit 2 – Deep Retrofit	10.4	15%
New 2 - High Standard For New Buildings	10.2	15%

League Tables of the Most Cost and Carbon Effective Measures

Table 25: League table of the most carbon effective measures, commercial sector

Commercial type	Measure	Description	Total carbon savings (Lifetime, Mt)
Retail	New 3	Advanced energy design guide 50%	26
Office	New 3	Advanced energy design guide 50%	20
Warehouse	New 3	Advanced energy design guide 50%	16
Retail	New 2	Advanced energy design guide 30%	16
Office	New 2	Advanced energy design guide 30%	14
Warehouse	New 2	Advanced energy design guide 30%	14
Office	Retrofit 2	Moderate-Deep Retrofit	6
Office	Retrofit 1	Shallow Retrofit	5
Retail	Retrofit 2	Moderate-Deep Retrofit	4
Retail	Retrofit 1	Shallow Retrofit	4
Warehouse	Retrofit 2	Moderate-Deep Retrofit	4
Warehouse	Retrofit 1	Shallow Retrofit	3

Table 25: League table of the most carbon effective measures, commercial sector

Commercial type	Measure	Description	$/tonne
Retail	Retrofit 1	Shallow Retrofit	-63
Office	Retrofit 1	Shallow Retrofit	-55
Warehouse	Retrofit 1	Shallow Retrofit	-38
Retail	Retrofit 2	Moderate-Deep Retrofit	-21
Office	New 2	Advanced energy design guide 30%	-17
Office	New 3	Advanced energy design guide 50%	-15
Office	Retrofit 2	Moderate-Deep Retrofit	1
Retail	New 3	Advanced energy design guide 50%	9
Retail	New 2	Advanced energy design guide 30%	15
Warehouse	New 2	Advanced energy design guide 30%	19
Warehouse	New 3	Advanced energy design guide 50%	19
Warehouse	Retrofit 2	Moderate-Deep Retrofit	35

4.3 The Industrial Sector

While Calgary is a major hub for the head offices of international energy firms, the city also has growing manufacturing, logistics, and food processing industries. The industrial sector consumed $220 million of energy in Calgary and contributed 2.3 Mt of GHG emissions in 2017, accounting for 15% of the total emissions and energy use in the city. The industrial sector includes a variety of different industrial types and processes, offering a range of opportunities for cost and emissions reduction. As industrial processes are often operating consistently over a twenty-four hour period, small changes in efficiency can have a large impact over time. In this study, four main types of processes were explored: Boilers and steam systems; furnaces and process heaters; cooling and refrigeration units; and motor driven equipment such as pumps, fans, and compressors. A given industrial unit may have many, one, or none of these processes at varying scales, making the results of this section dependent on the individual unit being looked at. Nevertheless, the results show certain trends that establish the actions that could be taken in a wide range of industrial units.

The Opportunity for Carbon Reduction: Investments and Returns

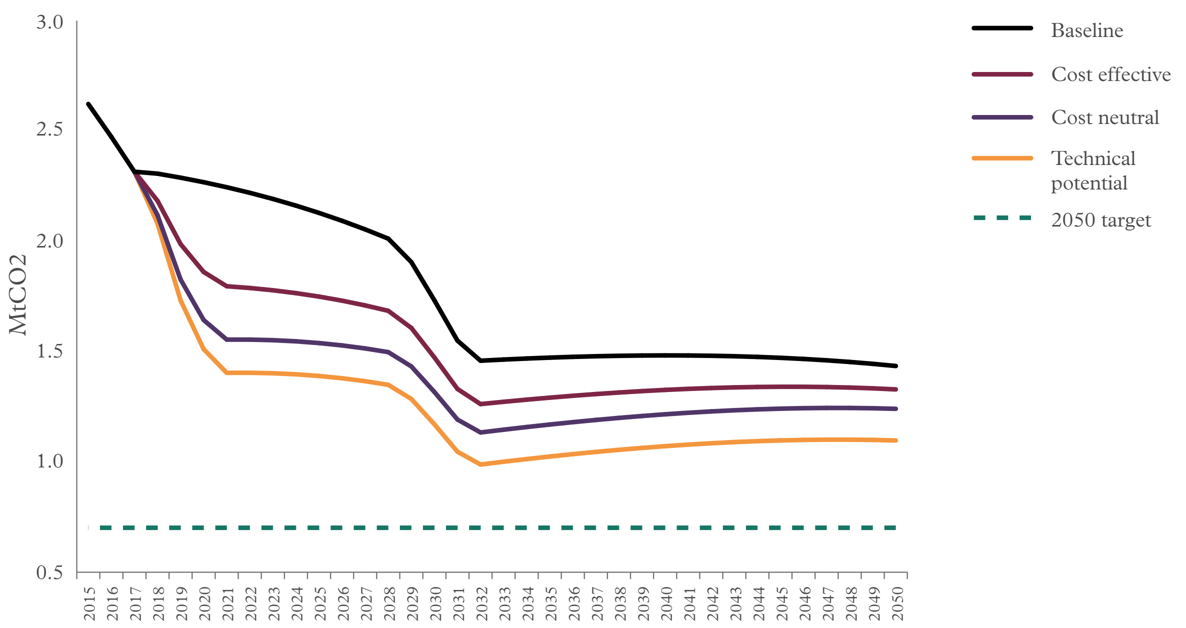
We find that investments in low carbon options in industry in Calgary could have a substantial impact on energy use, bills and emissions across the city. We forecast that by 2050 carbon emissions could be reduced by:

-7.2% through cost effective investments that would pay for themselves (at an 8% interest rate), over their lifetime. This would require investment of $1.0 billion, generate average annual energy savings of $118 million, and payback the original investment in 6 years.

-13.3% through cost neutral investments that could be made at no net cost to the city's economy if the economic returns from cost effective investments were reinvested in further actions. This would require investment of $5.8 billion, generate average annual energy savings of $176 million and payback the original investment in 24 years.

-23.3% with the exploitation of the technical potential of current opportunities to reduce carbon emissions. This would require investment of $86.5 billion, generate average annual energy savings of $199 million and payback the original investment in 35 years.

Figure 10: Baseline and scenario emissions for the industrial sector



Employment impact

Low carbon investments cannot be realised without skilled tradespeople, engineering know-how and support from a variety of industries across the city.

-Investments in cost effective measures in the industrial sector could generate nearly 700 years of employment. Over the period to 2050 this could mean steady employment for 14 Calgarians.

-Investments in cost neutral measures in the residential sector could generate nearly 4000 years of employment. Over the period to 2050 this could mean steady employment for more than 70 Calgarians.

-Investment in all possible measures in the residential sector could generate more than 6500 years of employment. Over the period to 2050 this could mean steady employment for more than 100 Calgarians.

These figures should be treated with caution and interpreted as indicative of the relative scale of potential impacts on employment under different scenarios. Particularily in the cost neutral and technical potential scenarios, constraints on the number of available skilled workers could dramatically limit employment impacts.

Discussion

Results from the industrial sector show that while the potential for energy and carbon savings is large, it is reltively smaller than the potential for other sectors of the Calgary economy. This can be attributed to the fact that industrial processes are typically closely monitored with maximizing efficiency and the economic case as a primary consideration. Driving specific actions in the industrial sector is generally beyond the scope of actions City policymakers have influence over. However, by understanding the scale of emissions and energy use in this sector, policymakers can better work with industrial energy users to fit industrial energy efficiency into the City's longterm carbon management plan. In this case, an important finding is that even in the scenario where all possible measures are implemented, emissions remain far above the 2050 target. This suggests that either further actions are needed, including potential actions from technologies not yet developed, or that other sectors in Calgary will need to increase their mitigation actions to makeup for the shortfall. Particular actions that were not investigated by this analysis, such as district energy, distributed energy, battery storage, and energy demand management, may show potential for implementation in this sector.

League Tables of the Most Cost and Carbon Effective Measures[14]

Table 27: Most carbon effective measures, industrial sector

Process	Process Step	Number of Measures	$/tonne
Motor-driven equipment	Fans	10	-$400 to $2600
Motor-driven equipment	Pumps	10	-$388 to 3800
Motor-driven equipment	Compressed Air Systems	18	-$300 to $455
Cooling and refrigeration	Refrigeration	10	-$176 to $7073
Boilers / Steam systems	Various	16	-$10 to $915
Furnaces / Process Heater	Furnaces	8	$41 to $1165

Table 28: Most carbon effective measures, industrial sector

Process	Process Step	Number of Measures	Carbon savings (ktCO2, lifetime)
Motor-driven equipment	Fans	10	186 to 1860
Motor-driven equipment	Pumps	10	230 to 1395
Motor-driven equipment	Compressed Air Systems	18	93 to 1395
Furnaces / Process Heater	Furnaces	8	40 to 1165
Boilers / Steam systems	Various	16	120 to 800
Cooling and refrigeration	Refrigeration	10	31 to 248

[14] Details on specific measures are available in the supplementary material

4.4 Land-Use and Distributed Energy

Urban form plays a fundamental role shaping urban processes, from travel patterns, to employment decisions and housing choices,,. Critically, in contrast with many other options for addressing GHG emission considered by the Climate Smart Cities team, land-use decisions are very hard to change, or 'un-do', in the future. While personal vehicles are replaced every 15-20 years and houses are rebuilt every 50-100 years, the structures of neighbourhoods and business districts can persist for far longer. How we build a growing city may therefore be one of the most important decisions we make towards meeting long-term goals like our climate change targets.

Calgary has a relatively low density compared with other major cities in Canada, approximately 1500 people per square kilometre compared with 4300 people per square km in Toronto, 4700 in Montreal and 5500 in Vancouver. In order to gradually increase density and support sustainable development the city has developed a Municipal Development Plan (MDP), and the Calgary Transportation Plan (CTP). These documents, supported by successive City Councils and written with support from a large set of urban stakeholders, established a 60-year strategy for urban growth.

Using the MDP and CTP to provide a baseline for what the City of Calgary will look like in 2050, this analysis considers two scenarios to understand the impact of urban form on urban GHG emissions and energy use. The first of these, the "MDP Plan", assesses the impact of existing policies as compared with a 'dispersed' scenario where the footprint of Calgary, and the number of single family detached homes, are not affected by the MDP and CTP. This scenario provides an assessment of the impact of policies the City has already implemented, and plans to implement, in order to achieve the targets of the MDP and CTP.

A second scenario considers the climate and economic impacts of an increase in the ambition of the MDP and CTP. Specifically, the "MDP+" scenario has the City of Calgary achieve the 2050 split between single family, townhouses and apartments anticipated by the MDP plan one decade earlier: In the MDP plan, single family homes decline from 58% of all dwellings in Calgary in 2018, to 47% in 2050 (while growing in absolute number by 31% across the period). In the MDP+ scenario this is achieved in approximately 2040. This scenario assesses whether a case can be made for the City to push beyond its existing targets for sustainable urban development.

The Opportunity for Carbon Reduction: Investments and Returns

We find that there is substantial opportunity in these areas to cut energy use, bills and emissions within Calgary. We find that by 2050 city-wide carbon emissions could be reduced by:

-3% by maintaining the city's MDP targets (these savings are already included in the baseline). This would generate net savings in investment in infrastructure of almost $20 billion, generate annual energy savings of $91 million, or a stream of savings with a net present value (at an 8% interest rate) of $3.5 billion between today and 2050.

-1.5% by increasing the ambition of the City's current MDP and CTP plans. This would generate net savings in investment in infrastructure of almost $9 billion, generate annual energy savings of $46 million, or a stream of savings with a net present value (at an 8% interest rate) of $2.3 billion between today and 2050.

-1.1% by investing in solar panels on 12500 new homes each year. This would require $2.2 billion in capital investment, generate average annual energy savings of more than $110 million, and payback the original investment in 11 years.

-0.5% by investing in solar panels on 500 commercial properties each year. This would require $1.3 billion in capital investment, generate average annual energy savings of $50 million, and payback the original investment in 15 years.

-1.1% by investing in solar panels on 12500 existing homes each year. This would require $4.0 billion in capital investment, generate average annual energy savings of more than $110 million, and payback the original investment in 19 years.

[15] Due to the high level of uncertainty no employment impacts are estimated from changes in land-use (Ahlfedlt et al 2017)

Employment impact

Low carbon investments cannot be realised without skilled tradespeople, engineering know-how and support from a variety of industries across the city[15].

-Investments solar panels on new homes could generate nearly 20,000 years of employment. Over the period to 2050 this could mean steady employment for 500 Calgarians.

-Investments in solar on commercial buildings could generate approximately 12,000 years of employment. Over the period to 2050 this could mean steady employment for 350 Calgarians.

-Investment solar on existing homes in the residential sector could generate 35,000 years of employment. Over the period to 2050 this could mean steady employment for more than 1000 Calgarians.

These figures should be treated with caution and interpreted as indicative of the relative scale of potential impacts on employment under different scenarios. Particularily in the cost neutral and technical potential scenarios, constraints on the number of available skilled workers could dramatically limit employment impacts.

Results from the MCA

Results from a multi-criteria analysis survey provide an indication of Calgarian's perceptions of some of the wider potential impacts of the different measures under consideration..

Results show that respondents see potential for net social, economic and environmental benefits from a number of interventions. Solar PV is seen to be a measure with significant potential for net benefits, particularly in improving human health and well-being. Both land-use measures are viewed as providing net economic benefits but the less aggressive of the two, 'best practices in green field development', is seen to have potential for a substantially larger impact. Distributed wind is seen to have a net neutral impact.

Table 29: MCA results for land-use and distributed energy measures

Measure	Score	% of maximum possible score
Solar PV	17.4	25%
Best practices in green field developments	11.0	16%
Combined Heat and Power (CHP)	10.3	15%
Heat Recovery and Geothermal Heating	9.5	14%
Compact city development	3.7	5%
Distributed Wind	0.3	0%

Discussion

While the impact on baseline emissions from land-use and distributed energy measures may seem small, actions in this sector have the potential to fundamentally alter energy use and carbon emissions in Calgary. Distributed solar presents a relatively poor case for investment; however it was ranked among the highest in its overall MCA score, suggesting broad public support. One challenge for this measure to contribute to Calgary's emissions targets lies in the fact that electricity from distributed solar is assumed to displace grid electricity. Therfore, as the electricity grid decarbonises the potential for impacts on emissions is reduced.

Urban form plays a fundamental role shaping urban processes and can affect emissions far into the future. Using the MDP and CTP to provide a baseline for what the City of Calgary will look like in 2050, this analysis considers two scenarios to understand the impact of urban form on urban GHG emissions and energy use. The first of these, the "MDP Plan", assesses the impact of existing policies as compared with a 'dispersed' scenario where the footprint of Calgary, and the number of single family detached homes, are not affected by the MDP and CTP. The second scenario considers the climate and economic impacts of an increase in the ambition of the MDP and CTP.

Both measures considered lead to substantial carbon savings. Maintaining the MDP plan saves more than 10Mt CO2 and nearly $20 billion in capital investment. The MDP+ scenario, over-and-above the savings in the MDP plan, produces substantial savings in emissions, energy use and capital expenditure. Realizing these actions will require coordination between the City, urban stakeholders, and neighbouring municipalities. Land-use decisions can have long lead time, impacts on large numbers of stakeholders, and can generate an unequal distribution of gains and losses. This analysis, supported by a large literature on urban density, shows that economic and climate benefits are possible, but realizing them will require overcoming challenges.

League Tables of the Most Cost and Carbon Effective Measures

In Tables 21 and 22 below, measures in blue are included in the cost effective scenario (CE), those in yellow are in the cost neutral scenario (CN), those in the technical potential scenario (TP) are in orange. Many actions are mutually exclusive and are therefore not included in any scenario.

Table 30: League table for the most carbon effective measures, land-use and distributed energy

Measure	total carbon saved (Mt)
MDP (in baseline)	12
MDP+	7
Scenario 1 solar (new residential)	7
Scenario 2 solar (commercial)	3
Scenario 3 solar (residential retrofit)	7

Table 31: League table for the most cost effective options, land-use and distributed energy

Measure	Cost per tonne
MDP+	-$326
MDP (in baseline)	-$299
Scenario 1 solar (new residential)	$22
Scenario 2 solar (commercial)	$71
Scenario 3 solar (residential retrofit)	$120

4.5 The Transportation Sector

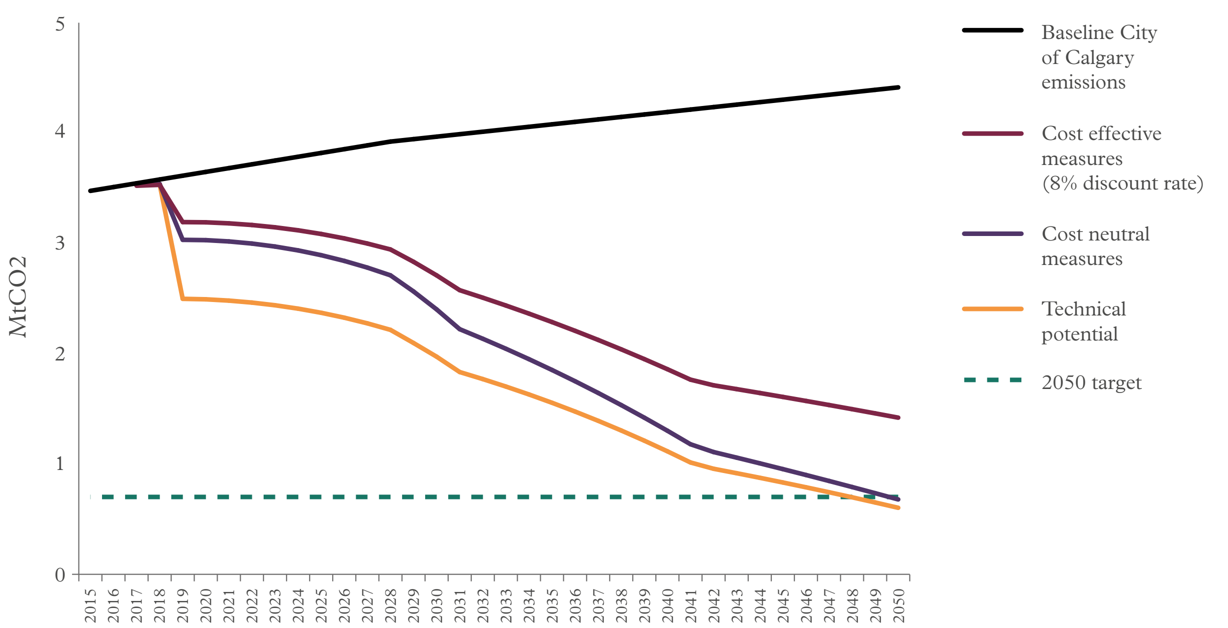
Emissions from transportation comprise approximately one-quarter of Calgary's emissions, or 3 tonnes per capita per year. This is slightly higher than for other Canadian cities, reflecting higher car ownership and higher vehicle kilometres travelled per person in Calgary. This leads to higher expenditure on fuel with the average Calgarian spending $1100 on gasoline and diesel in 2017. In the context of the city's target of reducing emissions by 80% from 2005 levels by 2050, the transportation sector is of particular significance as baseline projections show transportation emissions continuing to rise through 2050, due to increases in vehicle kilometres per capita and an increasing population.

The Opportunity for Carbon Reduction: Investments and Return

Investments in fuel efficient and low carbon transportation in the city could substantially reduce energy use, costs and emissions. As illustrated in Figure 8, we find that by 2050 carbon emissions could be reduced by:

- 68% through cost effective investments that would pay for themselves (at an 8% interest rate), over their lifetime. This would require investment of $13.6 billion, generate average annual energy savings of $2.7 billion, and payback the original investment in 5 years.
- 85% through cost neutral investments that could be made at no net cost to the city's economy if the economic returns from cost effective investments were reinvested in further actions. This would require investment of $59.0 billion, generate average annual energy savings of $3.2 billion and payback the original investment in 18 years.
- 86% with the exploitation of the technical potential of current opportunities to reduce carbon emissions. This would require investment of $78 billion, generate average annual energy savings of $3.7 billion and payback the original investment in 21 years.

Figure 11: Baseline and scenario emissions for the transportation sector



Employment impact

Low carbon investments cannot be realised without skilled tradespeople, engineering know-how and support from a variety of industries across the city[16].

- Investments in cost effective measures in the transportation sector would have a very small impact on employment in the city. This is due to the fact that almost all measures in the cost effective scenario involve alternative fuel vehicles whose impact on employment is assumed to be net zero.
- Investments in cost neutral measures in the residential sector could generate nearly 300,000 years of employment. Over the period to 2050 this could mean steady employment for more than 5000 Calgarians.
- Investment in all possible measures in the residential sector could generate more than 650,000 years of employment. Over the period to 2050 this could mean steady employment for more than 13000 Calgarians.

These figures should be treated with caution and interpreted as indicative of the relative scale of potential impacts on employment under different scenarios. Particularily in the cost neutral and technical potential scenarios, constraints on the number of available skilled workers could dramatically limit employment impacts.

Results from the MCA

Results from a multi-criteria analysis survey provide an indication of Calgarian's perceptions of some of the wider potential impacts of the different measures under consideration.

Results show that respondents see the potential for both net positive and negative impacts from actions in the transportation sector. Investments in transit and increasing non-motorized transportation are viewed to have a positive social, economic and environmental impact. In particular, these measures scored high on the criteria 'capacity to improve human well-being'. In contrast, 'biofuels', 'reduced car ownership' and 'increased parking levies' scored net negative, with their lowest scores coming from the criteria 'political acceptability'.

Table 32: MCA results for the transportation sector

Measure	Score	% of maximum possible score
Increased cycling and walking to work	13.0	19%
Transit wait times reduced (25% - 50% target)	11.0	16%
Free transit	10.8	15%
Carpooling	2.8	4%
Compressed natural gas heavy vehicle transportation	0.4	1%
Electric vehicles (5-50% target by 2030)	-0.9	-1%
Hybrid vehicles (5-50% target by 2030)	-1.0	-1%
Biofuel (B20)	-7.1	-10%
Reduced car ownership (20-40% target)	-8.0	-11%
Increasing parking levies	-11.1	-16%

[16] Due to the high degree of uncertainty, net zero impacts on employment are assumed from a shift towards hybrid and electric vehicles (T&A 2017).

Discussion

Transportation is the only sector of emissions anticipated to grow between 2017 and 2050 in Calgary. Suprisingly, it is (arguably) also the sector with the largest potential for reductions in energy use and emissions. Cost effective actions could cut emissions nearly 70% while generating economic returns, while cost neutral options could increase emissions reductions to 85%.

The most cost effective of these actions are in shifting private vehicles owners to hybrid cars, which currently command a relatively small price premium, and electric vehicles, whose prices are currently higher relative to convention vehicles, but falling quickly. Public transportation measures, including eliminating the cost of the public transportation network, expanding the size of the network, and increasing the frequency of service, can significantly affect transportation emissions, but were found to be very costly. This suggests that public transportation investments, while important, and potentially necessary, for a variety of reasons, may not be the most effective means of affecting urban GHG emissions.

While policymakers in Calgary have significant influence over public transportation, their influence over private transportation is more limited. In order to maximise the energy and carbon impacts of public transportation measures, policymakers can pair land-use measures that increase density with investments in the transportation network.
To encourage a shift to hybrids and electric vehicles policymakers can ensure charging stations are available, and could consider more ambitious actions, like designated parking, congestion charges for certain vehicle types, and a corporate vehicle strategy.

Table 33: League table of the most carbon effective measures, transportation sector

Transport subsector	Fuel	Intervention	Carbon savings (Mt)
Petrol cars	Gasoline	Electric (medium)	26.0
Petrol cars	Gasoline	Electric (light)	24.4
Public transport	All fuels	Biofuel (B20)	17.4
Petrol cars	Gasoline	Hybrid (medium)	16.4
Petrol cars	Gasoline	Hybrid (light)	15.5
Public transport	All fuels	Increasing parking levies ($8/hr - $32/d)	12.6
Public transport	All fuels	Reduced car ownership (40%)	8.3
Petrol cars	Gasoline	Electric (heavy)	7.2
Public transport	All fuels	Increasing parking levies ($3/hr - $12/d)	6.9
Petrol cars	Gasoline	Hybrid (heavy)	4.6
Public transport	All fuels	Free transit	4.4
Public transport	All fuels	Reduced car ownership (20%)	3.7
LGV	Diesel	Electric	3.3
Public transport	All fuels	100$ carbon tax	2.5
Public transport	All fuels	Expansion of transit coverage (25%)	2.1
LGV	Gasoline	Electric	1.3
HGV	Diesel	Electric	1.1
LGV	Diesel	Hybrid	0.8
Public transport	All fuels	Carpooling	0.7
Diesel cars	Diesel	Electric (medium)	0.7
Motorcycles	Gasoline	Electric	0.4
Diesel cars	Diesel	Hybrid (medium)	0.4
Diesel cars	Diesel	Electric (heavy)	0.4
Diesel cars	Diesel	Electric (light)	0.3
LGV	Gasoline	Hybrid	0.3
Diesel cars	Diesel	Hybrid (heavy)	0.3
HGV	Diesel	Hybrid	0.2
HGV	Diesel	CNG	0.2
Diesel cars	Diesel	Hybrid (light)	0.2
Buses	Diesel	Electric buses	0.2
Public transport	All fuels	Expanded non-motorized transport (biking and walking)	0.2
Buses	Diesel	CNG	0.0
Buses	Diesel	Hybrid buses	0.0
Public transport	All fuels	Expansion of transit capacity (50% increase)	0.0

Table 34: League table of the most cost effective measures, transportation sector

Transport subsector	Fuel	Intervention	$/tonne
Public transport	All fuels	100$ carbon tax	-$280
Public transport	All fuels	Carpooling	-$277
Public transport	All fuels	Increasing parking levies ($8/hr - $32/d)	-$275
Public transport	All fuels	Increasing parking levies ($3/hr - $12/d)	-$274
Buses	Diesel	Electric buses	-$252
LGV	Gasoline	Electric	-$245
LGV	Diesel	Electric	-$245
HGV	Diesel	Electric	-$246
HGV	Diesel	CNG	-$189
LGV	Gasoline	Hybrid	-$165

LGV	Diesel	Hybrid	-$164
Petrol cars	Gasoline	Hybrid (light)	-$140
HGV	Diesel	Hybrid	-$137
Petrol cars	Gasoline	Hybrid (medium)	-$133
Diesel cars	Diesel	Electric (light)	-$108
Petrol cars	Gasoline	Hybrid (heavy)	-$101
Diesel cars	Diesel	Electric (heavy)	-$91
Diesel cars	Diesel	Hybrid (heavy)	-$82
Diesel cars	Diesel	Electric (medium)	-$79
Diesel cars	Diesel	Hybrid (light)	-$78
Buses	Diesel	CNG	-$74
Petrol cars	Gasoline	Electric (light)	-$73
Diesel cars	Diesel	Hybrid (medium)	-$69
Petrol cars	Gasoline	Electric (heavy)	-$65
Petrol cars	Gasoline	Electric (medium)	-$48
Buses	Diesel	Hybrid buses	-$45
Public transport	All fuels	Biofuel (B20)	$20
Public transport	All fuels	Free transit	$198
Public transport	All fuels	Reduced car ownership (20%)	–
Public transport	All fuels	Reduced car ownership (40%)	–
Public transport	All fuels	Expanded non-motorized transport (biking and walking)	>1000
Public transport	All fuels	Expansion of transit coverage (25%)	>1000
Public transport	All fuels	Expansion of transit capacity (50% increase)	>1000

4.6 The Waste Sector

The waste sector in Calgary contributes approximately 5% of urban emissions, or 0.6 tonnes of CO2e per person per year, similar to the level of emissions across Canadian municipalities. While this level of emissions is much smaller than the contribution of transportation or household energy use to Calgary's greenhouse gas footprint, there are a number of reasons to focus on the sector.

While emissions in other sectors of the city are anticipated to fall over the coming decades, waste production per capita across Canada continues to rise. Waste emissions can, in some cases, be removed readily and easily with currently available technologies in ways that are economically beneficial. Reducing waste and waste emissions can have broader socio-economic impacts, affecting public health, creating jobs and reducing Calgary's costs. Finally, while direct emissions from waste in Calgary are relatively low, strategies which reduce the use of goods and materials in the city can reduce emissions "upstream" in other jurisdictions where those good and materials are made. While the impact of reduced "upstream" emissions is not assessed in this analysis, research suggests that these "upstream" emissions can add 50% to a city's total.

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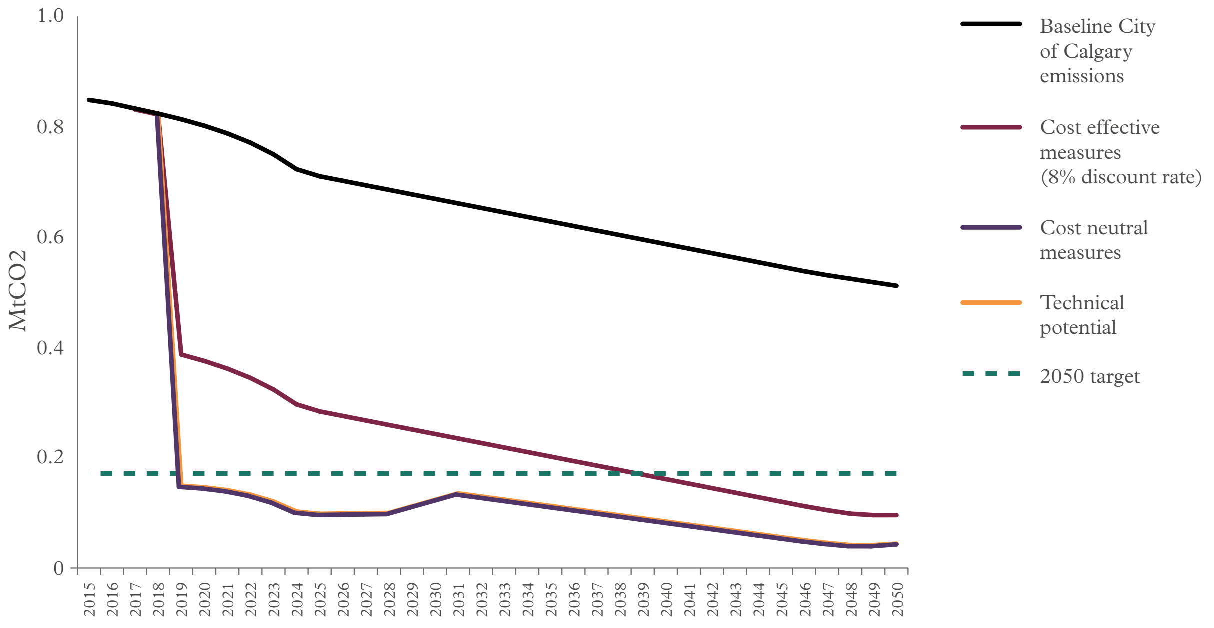
-81.2% through cost effective investments that would pay for themselves (at an 8% interest rate), over their lifetime. This would require investment of $533 million, generate average annual energy savings of 25 million, and payback the original investment in 16 years.

-91.4% through cost neutral investments that could be made at no net cost to the city's economy if the economic returns from cost effective investments were reinvested in further actions. This would require investment of $560 million, generate average annual energy savings of $42 million and payback the original investment in 45 years

Figure 12: Baseline and scenario emissions for the waste sector



Employment impact

Low carbon investments cannot be realised without skilled tradespeople, engineering know-how and support from a variety of industries across the city. At the same time, investments can lead to jobs being replaced by technology.

-Investments in cost effective measures in the waste sector could generate losses of more than 2500 years of employment. Over the period to 2050, this could mean the loss of 50 jobs for Calgarians. This is due to the fact that landfills require more workers than waste-to-energy plants.

-Investments in cost neutral measures in the waste sector could generate nearly 3,000 years of employment. Over the period to 2050 this could mean steady employment for more than 50 Calgarians (after accounting for losses from waste-to-energy investments).

These figures should be treated with caution and interpreted as indicative of the relative scale of potential impacts on employment under different scenarios.

Results from the MCA

Results from a multi-criteria analysis survey provide an indication of Calgarian's perceptions of some of the wider potential impacts of the different measures under consideration.

Results show that respondents see the potential for both net positive and negative impacts from actions in the waste sector. 'Waste prevention' received the highest overall score, with its highest results from the 'human health and wellbeing' criteria. 'Incineration' and 'Landfill gas flaring' were both seen to have a potential net negative impact, with their lowest scores in the criteria 'human health and wellbeing'.

Table 35: MCA results for the waste sector

Measure	Score
Prevention (5-10% target)	24.5
Land-fill gas utilization	15.3
Energy from waste (Combined Heat and Power)	7.4
Energy from waste – electricity	4.6
Landfill gas flaring	-5.1
Incineration	-12.4

Discussion

Emissions from the waste sector are relatively small, representing <5% of total GHG emissions from the city. Importantly however, large amounts of energy and emissions are released outside of the city in order to produce the goods that ultimately end up as waste. Taking these emissions into account, the role of the waste sector looms much larger: emissions from food and beveridge consumption alone have been found to account for ¼ of emissions from UK cities. When these 'upstream' emissions are taken into account in their entirety emissions from wealthy cities have been found to double or even triple.

Measures that turn waste into energy were found by this analysis to impact significantly on carbon emissions while providing a nominal return on investment. While these actions actions are technically possible, they would require significant capital investment (that could otherwise be invested in other low carbon options), and coordination between a number of municipalities and private waste services. Bringing about this coordination could generate additional costs and challenges to realizing these actions.

Actions to reduce the production of waste, based on programs implemented in other Canadian cities, were found to have relatively smaller impacts of emissions. While the economic case is relatively poor, compared with measures in other sectors of this analysis, the amount of required investment is modest, sugguesting that realizing investment may be easier. Finally, preventative measures may have the largest potential to have impacts on emissions outside of Calgary ("upstream"), by reducing the amount of goods and services that need to be produced for Calgarians. League Tables of the Most Cost and Carbon Effective Measures

In Tables 27 and 28 below, measures in blue are included in the cost effective scenario (CE), those in yellow are in the cost neutral scenario (CN), those in the technical potential scenario (TP) are in orange. Many actions are mutually exclusive and are therefore not included in any scenario.

Table 36: League table of the most carbon effective measures, waste sector

Measure	$/tCO2e
Energy from waste (CHP)	17
Energy from waste - electricity	15
LFG utilization	15
Incineration	14
10% Prevention	2
LFG flaring	1
5% Prevention	1

Table 37: League table of the most cost effective measures, waste sector

Measure	$/tCO2e
Incineration	-$8
Energy from waste (CHP)	-$6
Energy from waste - electricity	-$4
LFG utilization	$0
LFG flaring	$2
10% Prevention	$10
5% Prevention	$11

Conclusions and Recommendations

The analysis presented in this report shows that business as usual modes of development in Calgary will put the city on a path that is incompatible with its targets for decarbonisation. It will also mean that Calgary overlooks significant opportunities to stimulate its economy, improve its energy security, create employment and generate a wider range of social benefits such as improved public health and reduced energy poverty through investments in energy efficiency and low carbon development.

The analysis also shows that there is a strong economic case for Calgary to pursue an ambitious and cost-effective low carbon development path that is consistent with its 2050 target for decarbonisation, at least until the early 2030s (see the cost-effective pathway in Figure 3). Although this would require total investments of over $12 billion, the analysis shows that in aggregate these investments would pay for themselves within 3 years before generating net returns of $1.7 billion per year in the city by 2030. These investments would also create 2,000 years of extra employment in the city. To this extent, the opportunity for cost-effective forms of low carbon development should be seen as an opportunity to secure a very significant economic stimulus package for the city.

It is important to note that a significant proportion of the investment required to enable a switch to this lower carbon development path could occur autonomously – for example where organisations or individuals invest in reducing their own energy use and carbon emissions in order to realise the associated benefits. A further proportion could be stimulated through new forms of policy such as improved building standards or requirements for decentralised energy to be integrated into new developments. More still could be realised by 'nudging' developments that would have happened anyway towards a more energy efficient and lower carbon path. Nonetheless, some of the required investment would undoubtedly need to be raised from different investors. Innovative ways of securing and deploying such investments - such as green bonds or revolving funds - could make this level of investment more achievable and ensure that more of the benefits of the investments are retained by actors within the city.

The analysis also suggests though that considering only the cost-effective options for low carbon development will mean that the city departs from the pathway towards its 2050 target in the early 2030s – at least with current technologies and under current conditions (again see Figure 3). Of course, this point of departure could be delayed if new technologies come on stream or if the cost-effectiveness of currently available technologies improves before then. This seems likely to some extent – and it could be encouraged through different forms of policy and new approaches in various instances.

Even with a coordinated, sustained and embedded approach, it seems very unlikely that these advances would completely close the gap between the cost-effective pathway and the path towards the 2050 target as depicted in Figure 3. In theory, the gap between these pathways could be closed if the city (or organisations within it) found a way of capturing and recycling some of the savings from the more cost-effective options and using these to subsidise investments in the less cost-effective options. This could be facilitated through innovative measures such as a city-level revolving fund. If such a fund had complete coverage and perfect efficiency, the analysis shows that the city could get very close to its 2050 target at no net cost, even with current technologies (see the cost-neutral pathway in Figure 3). The incentives for developing such a fund, or something that approximates it, are huge. The cost-neutral pathway would see investments of over $100 billion creating 26,000 years of extra employment in the city. The prospect of that scale of economic stimulus in the city could be enough to trigger significant innovations in low carbon financing.

The results therefore demonstrate that Calgary could meet and exceed its contribution to national carbon reduction targets. At a national scale, Canada has committed to cutting emissions 30% by 2030 from 2005 levels. The analysis shows that Calgary could reduce its emissions 35% below its 2005 levels by 2030 by applying only cost-effective actions, and by 53% if the returns from cost effective actions were reinvested[17]. Climate action is therefore not just an opportunity for economic, social and environmental returns, but an opportunity for Calgary to showcase itself as a leader in the low carbon economy – one of the fastest growing sectors in OECD countries.

The analysis in this report makes a case for Calgary to be a leader in the low carbon economy. It also offers some guidance on most cost and carbon effective and publically acceptable ways of assuming this leadership position. However, it is important to emphasize that the economic lens through which much of this analysis has been conducted provides only a limited perspective on the rationale for climate action in Calgary. Clearly the case for action must be viewed in the context of a much wider set of criteria that consider the future of the city in broader terms. But the main conclusion of the report is that the shift towards a lower carbon development path for Calgary cannot be dismissed on technical or economic grounds – an economically and technologically viable transition to a low carbon Calgary is entirely possible.

Acknowledgements

This project was funded by the City of Calgary with support from The University of Calgary and the ESRC Centre for Climate Change Economics and Policy at the Unversity of Leeds. The authors gratefully acknowledge the support that has been provided by the City of Calgary, and in particular Brit Samborsky, Claire Beckstead, Eric MacNaughton, Dick Ebersohn, Dan Fox, Warren Brooke and Hugo Haley. We would also like to extend our thanks to the UK Foreign and Commonwealth Office and especially to Caroline Saunders.

[17] This analysis assumes that Calgary's contribution to national emissions reduction targets should be the same proportion of current emissions. In reality, land-use change in Canada is likely to significantly reduce the emissions reductions required from urban centres.

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2. Research from a large set of global cities suggests that 14-24% of urban GHG emissions can typically be reduced with actions that generate net economic returns to investors (Gouldson et al 2015).
3. Climate Smart Cities Calgary Reference Document (2018). Available from www.climatesmartcities.org
4. Note on the scenarios or pathways:
   Cost effective: The set of all measures that generate a positive economic return;
   Cost neutral: The set of measures that generates the largest savings in GHG emissions while maintaining an indicated rate of return across all measures greater than zero; Technical potential: The set of measures that generates the largest savings in GHG emissions.
5. For a small number of actions in the waste sector, energy use increases when carbon emissions decline. Across the other sectors and actions within this report, energy use reductions lead directly to GHG emissions savings.
6. Employment generation numbers should be treated with a high degree of caution. While a substantial body of research in North America and Europe establishes that investments in energy efficiency and low carbon development can generate increased employment – even after considering the jobs lost in other industries from diverted investment – the impacts of many types of investments are uncertain, especially for the cost neutral and technical potential scenarios. Electric vehicles for example are assumed to have a zero net impact on employment in this analysis – although arguments can be made both for job creation and job losses, the net impact is uncertain as they could require less maintenance, thereby leading to job losses in auto repairs, but lower transportation costs could also stimulate the economy and help to generate jobs in many sectors. The impacts of investments on employment are also highly dependant on economic conditions. If unemployment is relatively high, the potential for net job creation is relatively large. However, as the economy reaches full employment, the number of net jobs created may be smaller. The net impacts of investments will also be affected by technical change, which typically reduces employment impacts.
7. It should be emphasised that the subset of the Calgary population participating in the survey was not representative. Respondents, were on average relatively older and had spent a longer period of time in receiving academic qualifications, and males were over-represented. Further, it should be noted that results reflect public opinion on the desirability of different low carbon measures without extensive information being provided. Nonetheless, these results provide an indication of where Calgarian's see potential for positive and negative social, environmental, and economic impacts from the measures investigated.
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13. Several measures were also added to the list of actions to be included in the MCA that were not modelled for their economic and carbon case. These include several distributed energy options. While the research team was not able to complete economic and carbon modelling of these options they are areas of potential further research.
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Climate Smart Cities

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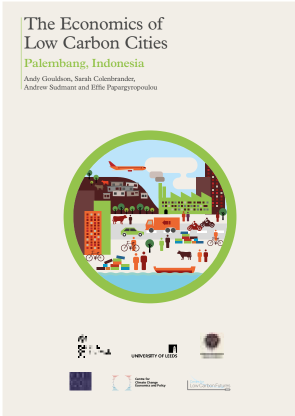
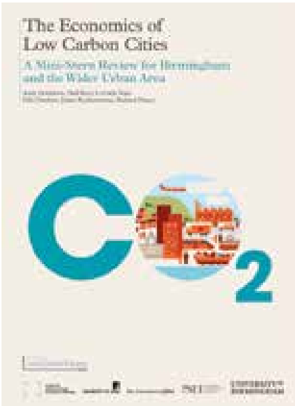


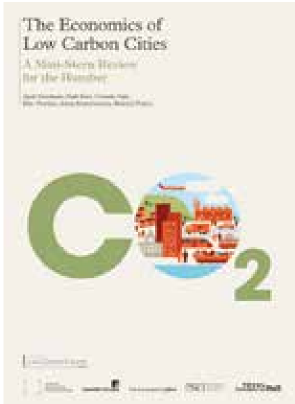
Palembang, Indonesia

Johor Bahru, Malaysia

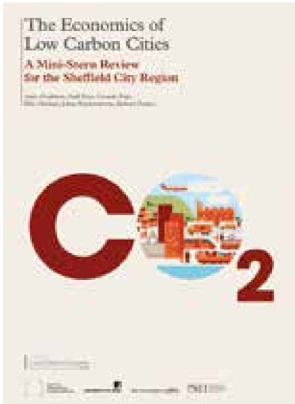
Leeds City Region



Birmingham and the Wider Urban Area



The Humber



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