

Exploring the Feasibility and Costs and Benefits of Solar Carports
for the Calgary Parking Authority

by

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EXECUTIVE SUMMARY

Introduction

Solar carports – structures that shade parked vehicles, protect vehicles from the elements, and generate renewable electricity using solar photovoltaic (PV) panels – present a unique and interesting opportunity for existing surface parking lots to be transformed into multi-use spaces that advance sustainability goals and generate added financial benefits for parking providers. By generating renewable energy, solar carports provide a means for public parking providers to offset energy costs, generate revenues by selling energy to the grid, and play a role in reducing greenhouse gas emissions in alignment with local, provincial, federal, and international commitments to address and mitigate climate change.

The client for this research, the Calgary Parking Authority (CPA), manages and operates off-street parking facilities for the City of Calgary, including 27 surface parking lots comprising 2,440 parking stalls. The CPA is interested in investments that will benefit its customers and the environment, offset energy costs and generate additional revenues and so this research asks: are solar carports feasible, and what are the costs and benefits to the agency and society if the CPA invests in solar carport infrastructure?

Methods

To answer this question, this research included a literature review, a legal and administrative review in the Calgary context, and a cost-benefit analysis. The literature review, which covered academic sources and grey literature, explored what is known about the costs and benefits of solar PV and solar carports, and sought to quantify the social benefit of offsetting greenhouse gas emissions.

Subsequently, a legal and administrative review identified opportunities and constraints that may affect the feasibility of solar carport investments in the Calgary context, including: provincial regulations; factors impacting electricity rates; municipal policy strategy, and bylaws; technical rules governing the electrical grid; and current subsidy programs that may lower the agency's initial investment costs.

Building on findings from the literature, legal, and administrative reviews, a cost-benefit analysis was conducted using data and estimates from the literature, City of Calgary, and potential solar PV suppliers to determine the NPV of a hypothetical solar carport project by calculating the costs and benefits for each year of the investment. Specifically, the analysis uses site data for a selected parking lot obtained from the City of Calgary's Energy Management Office and cost estimates provided by ENMAX Solar. To forecast commodity costs, including pool price and wholesale electricity prices, the cost-benefit analysis utilizes existing forecasts prepared by third-party organizations including the Calgary-based EDC Associates Ltd. and the Alberta Electric System Operator (AESO).

To calculate the benefits of offsetting greenhouse gas emissions through solar carports, this research used estimates for the marginal cost of abatement posited by Jaccard,

Hein and Vass (2016, p. 32), recognizing that even those estimates may not adequately value the cost of carbon emissions to society or represent what it will cost to achieve carbon reduction targets.

In accordance with the literature, the base case for this analysis was calculated using a social discount rate of 3.5 per cent, with sensitivity analyses for 0.0, 2.5, and 7.0 per cent social discount rates, recognizing that environmental investments occur in the context of climate change and to account for the expected long-term benefits associated with investments that reduce greenhouse gas emissions.

Although transfers between entities are traditionally excluded from cost-benefit analysis, this analysis included calculations to determine the net agency cost to the CPA, as this is an important consideration that would impact a decision to pursue a solar carport project. To address this, the cost-benefit analysis for this project considered the full project costs and added a potential subsidy to show the net costs to the agency. By excluding the portion of the subsidy and GST paid by Calgarians, the analysis further shows the net social benefits of a solar carport project.

Findings

In Alberta, microgenerators can produce renewable energy and sell surplus energy to grid in accordance with the Alberta Microgeneration Regulation. Microgenerators are compensated at consumer and pool price rates depending on the size of their system, but future electricity prices are uncertain due to a variety of factors, including changes to Alberta's electricity system that are currently underway. Under the current framework, it is more beneficial for microgenerators to consume all of the energy they produce onsite.

Although there is a regulatory basis for microgenerators to receive compensation for the energy they produce, consume and sell, it is not currently possible for microgenerators to export surplus energy to the grid in all parts of the City due to technical constraints. Microgenerators cannot export to the grid within ENMAX's secondary network boundaries, which are in place to ensure reliable service. Currently, it could be feasible to install solar carports at ten surface parking lots owned by the City and managed by the CPA that are located outside of the secondary network. Sites that are likely to have surface parking for the next 25 to 40 years are ideal, as this is the expected lifespan for a solar carport project.

This research, including a cost-benefit analysis for a hypothetical solar carport project, reveals that solar carports are an expensive investment – more expensive than other solar PV applications, such as rooftop solar – because of the high cost of the aluminum carport structure and foundation piles that may be required depending on site characteristics. Although solar carports are more beneficial in scenarios where electricity prices are higher, there would be a net cost to the agency over a 25-year period, even if the CPA received the maximum subsidy that may be available in the current context. Decreases in infrastructure costs, increases in electricity prices, increases in subsidies, and increased onsite consumption would make solar carports a more beneficial investment for the CPA.

While solar carports are expensive and may be expected to result in net costs based on current cost estimates and electricity price forecasts, they present an opportunity to contribute to local public policy objectives to reduce carbon emissions and are well aligned with local policies, plans and strategies. In the base case analysis (3.5 per cent social discount rate), considering the social value of avoided emissions, a solar carport project would have a net cost to society from the Calgarian perspective of \$212 per stall over the 25-year lifespan of a solar carport installation. In sensitivity analyses using lower social discount rates, the results show positive net benefits to society in both electricity price scenarios. If solar carports are considered an environmental investment that will provide long-lasting benefits by reducing carbon emissions for the benefit of future generations, they are arguably more beneficial to society.

Recommendations

Based on these research findings, there are six key recommendations for the CPA to consider as it works to identify opportunities for investments that will enhance environmental sustainability and generate benefits for Calgarians.

1. The CPA should actively work with the City to identify solar PV projects in parking contexts that will make better use of land designated for parking, create social benefits, and contribute to City sustainability objectives.
2. The CPA should exhaust opportunities for rooftop solar PV applications that may be less expensive but result in the same or greater financial and social benefits. In particular, the CPA should consider investing in solar infrastructure for the roof of the municipal impound lot.
3. The CPA should monitor the factors that impact the costs and benefits associated with solar carports and take advantage of opportunities that would create a more cost-effective investment. For example, if the cost of aluminum decreases or electricity rates increase, solar carport investments may become more cost-effective.
4. The CPA should do further work to determine if solar carports would be feasible at the ten sites identified in this report. This would involve identifying the long-term plans for each location, what known utilities exist underground, and the solar potential for each site.
5. If the CPA chooses to engage in further work to determine economic viability of solar investments, new cost-benefit analyses should consider additional parametric assumptions and include broader sensitivity analysis, looking at different cost and benefit pricing scenarios and more social discount rates.
6. The CPA should consider potential investments in solar PV as part of future planning and monitor factors that may make solar infrastructure more feasible or beneficial in the future, such as changes to the technical grid constraints downtown or increases in energy consumption that may come with increased demand for electrical vehicle charging. The fact that solar carports are currently an expensive investment does not negate their benefits or opportunities to make surface parking lots a more sustainable use of land.

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INTRODUCTION AND BACKGROUND

Introduction

Amid climate policy and greenhouse gas emissions reduction targets set at various levels of government, public and private entities worldwide have begun to explore the potential to generate solar power in parking lots by constructing solar carports and canopies – structures, much like traditional carports, with solar photovoltaic (PV) panels under which motor vehicles can park. Solar carports present an opportunity for parking providers to use existing surface parking assets as multi-purpose spaces to advance sustainability goals and create additional revenue or cost savings by generating electricity (Boychuk & Oelke, 2017, para. 1). However, it is necessary for organizations to understand the full range of costs, benefits, barriers and opportunities associated with solar carports so that they can make informed capital investment decisions.

This research asks: are solar carports feasible, and what are the costs and benefits of solar carports for the agency and society? This report investigates the costs, benefits, and overall feasibility of municipal public investment in solar carports for surface parking lots in the Calgary context. Specifically, using a hypothetical solar carport project for a surface parking lot owned by the City of Calgary and managed by the Calgary Parking Authority (CPA) this report identifies:

1. The costs and benefits of investing in solar carports in surface parking lots, including benefits to society associated with offsetting carbon emissions through the production of renewable energy, on a cost-per-stall basis;
2. Considerations affecting the feasibility and viability of installing solar carports in surface parking lots; and
3. Circumstances and conditions where it would be optimally beneficial for the City and the CPA to invest in solar carport infrastructure.

Background

Public Parking Management in Calgary

The CPA, the client for this research, manages and operates designated off-street parking facilities for the City of Calgary and is responsible for advising City Council and City business units on matters related to parking (Calgary Parking Authority Bylaw, 2017, pp. 1-3). The CPA operates at arm's length from other City business units and is governed by a City Council committee that makes recommendations to Council about the CPA's operating and capital budgets. The CPA operates without any municipal tax revenues and returns the greater of 65 per cent of net revenues or \$11 million to the City each year (Calgary Parking Policies, 2017, p. 9). The CPA's retained net revenues are used to finance existing and future capital and operating requirements (Calgary Parking Authority Bylaw, 2017, p. 3; Calgary Parking Policies, 2017, p. 9), which include ongoing maintenance of existing parking structures (i.e. surface parking lots and parkades).

At present, the CPA manages and operates 27 surface parking lots comprising 2,440 parking stalls (Calgary Parking Authority, 2018, p. 7). Twenty-four of these lots are owned or leased by the City of Calgary and of those, the CPA is the sole steward of seven lots acquired to provide parking. Seventeen, including three that are jointly stewarded by the CPA, are stewarded in whole or in part by other City business units or entities, including Roads, Parks, Real-Estate and Development Services, and the Calgary Municipal Land Corporation (CMLC) (i.e. the land was acquired by those business units). Three are owned by the Calgary Board of Education (CBE). Although the CPA manages and operates these lots, those other entities may eventually develop that land for other purposes. Additionally, the CPA currently provides parking services for a number of surface lots owned by third-parties, which include private lot owners and City partners, such as the Calgary Zoo, Telus Spark, and Heritage Park. A summary of current surface parking lot assets managed and operated by the CPA is provided in Appendix A.

The CPA is interested in investment opportunities that will benefit its customers and the environment, offset energy costs, and help to generate additional revenues. As examples, the CPA offers free electric vehicle (EV) charging in several of its parkades and is expecting to receive a donation of EV charging stations from Tesla later this year. In 2017, the CPA upgraded ParkPlus machines, which accept payment for parking in CPA managed lots, to be entirely solar powered (Calgary Parking Authority, 2017, para. 4); however, the CPA has not yet investigated other opportunities to utilize solar power for its facilities and infrastructure and its EV charging infrastructure currently draws electricity from the grid.

Solar Carport Technology

Solar carport and canopy projects of varying scales have been constructed in diverse locations across the world including France (Group Renault, 2011, para. 8) and numerous places in the United States including Arizona, California, Maryland, Massachusetts, New York, and Washington (Mooney, 2015, paras. 3-17). Currently, there are two solar carport installations in Alberta: the first was installed by the Regional Municipality of Wood Buffalo in Fort McMurray (Christian, 2014, paras. 1-33) and the second was installed by a commercial retail company, Simons, in Edmonton last year (Ma, 2017, paras. 2-17). Examples of solar carport installations are illustrated in Appendix B.

Solar carport or canopy installations are a relatively new technology and are more expensive than typical roof or ground mounted systems because of the unique specifications required (Alghamdi, Bajah & Wu, 2017, pp. 18-19; Mooney, 2015, para. 7). Unlike rooftop or ground mounted systems, solar carports must be built on structures tall enough that vehicles can park under them and these structures must be resistant to vehicular impact. Despite these unique specifications and high costs that have made such investments prohibitive in the past, manufacturing and installation costs are becoming increasingly affordable (Branker, Pathak & Pearce, 2011, p. 4475).

Reducing Greenhouse Gas Emissions

A growing body of scientific research shows that climate change is increasingly impacting Canada's natural environment, economy, and Canadians' physical health (Warren & Lemmen, 2014, pp. 2-5). Canada's average temperature increased by 1.5 degrees Celsius between 1950 and 2010, double the global average (p. 6), and the United Nations' Intergovernmental Panel on Climate Change (IPCC) recently issued a report warning that if temperatures continue to rise large scale and widespread extreme weather events are likely to increase in both frequency and intensity, causing significant costs and negative effects for communities (IPCC, 2018, pp. 13). To address this and mitigate the negative effects of warming, Canada, as a signatory to the Paris Agreement, has committed to reducing its greenhouse gas emissions to hold the increase in global average temperature to below two degrees Celsius above pre-industrial levels and the nationally determined contribution (NDC) to achieve the Paris Agreement's goals includes a pledge to reduce the nation's greenhouse gas emissions by 30 per cent below 2005 levels by 2030 (Government of Canada, 2017, pp. 1-5).

Locally, the City of Calgary's long-range sustainability plan, *imagineCALGARY*, sets targets to decrease the city's greenhouse gas emissions by 50 per cent from 1990 levels and increase use of low-impact renewable sources to comprise 30 per cent of energy consumption by 2036 (City of Calgary, 2013, pp. 5-8). Despite these ambitious goals, Calgary's greenhouse gas emissions and energy use have increased since those targets were first set; in 2016, Calgary's emissions totaled 3.1 million tonnes, compared to 1.9 million tonnes in 2006 (Economic Development and Trade, 2016, table 1). However, increased use of solar power as a low-emission renewable energy source, through various means including microgeneration, has been identified as a key strategy that will have a significant impact on reducing Calgary's carbon footprint (Row, Welk, Lemphers & Cobb, 2011, pp. 6, 21; City of Calgary, 2013, p. 14). Calgary is considered an ideal location for solar technology as it receives an average of 2,396 hours of sunlight each year (City of Calgary, 2017, para. 1). It is estimated that Calgary could generate 1,500 GWh of solar energy per year by 2036, which would comprise approximately 16 per cent of total electricity consumption and would reduce city-wide greenhouse gas emissions by approximately two per cent (Row et al., 2011, p. 23). Opportunities for large scale solar PV installations are typically limited to rooftop installations in densely populated areas because of a lack of space, but surface parking lots, which cover enormous surface areas in cities and are generally underutilized as single use spaces, present an untapped opportunity to generate energy in urban environments (Alghamdi, Bajah & Wu, 2017, pp. 2, 20).

Since more than one-third of greenhouse gas emissions in Calgary are transportation related (City of Calgary, 2018, para. 15), solar carports provide a unique opportunity for existing land assets used as parking lots to add value to the City beyond being a place to store vehicles, transforming parking lots into spaces that advance the City's sustainability goals. If found to be viable investments, solar carports will help to offset the negative impact that gasoline-powered vehicles have on the environment by generating energy to meet base and peak load needs for our electricity system and contributing to reduced greenhouse gas emissions (Alghamdi, Bajah & Wu, 2017, pp. 2-7, 19-20; Erickson & Jennings, 2017, pp. 48-49; Golden, 2006, p. 20; Golden,

Carlson, Kaloush & Phelan, 2007, p. 882; Rowlands, 2005, p. 833). Additionally, solar carports present an opportunity for parking providers to generate additional revenue to support parking operations (Alghamdi, Bajah & Wu, 2017, p. 20; Rowlands, 2005, p. 833). Investment in solar carports could potentially benefit all Calgarians through increased financial returns from the CPA to the City each year.

Although this research is being undertaken for the CPA in the Calgary context, its findings will have implications for public and private parking providers in all jurisdictions. For example, several other City of Calgary business units, including Calgary Recreation, Calgary Parks, and Calgary Transit, operate large surface parking lots across Calgary. Other possible applications include school, hospital, and commercial parking lots. It will also have implications for open air parkades, which do not have roofs and may also benefit from solar canopy infrastructure. This research will provide surface parking lot owners with information about various factors that will help them to understand the circumstances where it is feasible and economically viable to invest in solar carports in their own context.

This report looks at both the financial costs and benefits of solar carports to the CPA and the City, as well as the broader societal benefits of investing in solar infrastructure. The latter considers the value of avoided emissions based on the marginal cost of carbon abatement. By exploring both economic and social rationales for investments in solar infrastructure, the existing literature on solar carports and conducting a cost-benefit analysis, this research will help the CPA to understand why, where, and when investments in solar carports may be viable to inform responsible and transparent long-term capital planning for the CPA and the City of Calgary. It also provides a basis for the CPA to look more closely at the possibility of installing solar carports in lots where it would be most beneficial for the City. Building on existing literature and by exploring this issue in the Calgary context, we can identify important factors and conditions that will impact the feasibility of solar carport projects (i.e. land use restrictions) so that these may be considered and addressed.

Organization of the Report

The remainder of this report consists of the following sections. The Research Plan section details the methodology used to address the research questions for this project. Subsequently, the Literature Review section explores what is already known about solar carport applications, including factors impacting their feasibility and the costs and benefits of investing in solar carport infrastructure. The Legal and Administrative Review section looks at policies and programs that present opportunities and constraints in the Calgary context. The section on Cost-Benefit Analysis Considerations details the data and assumptions that were used to conduct a cost-benefit analysis for a specific hypothetical solar carport project in a real surface parking lot owned by The City of Calgary and managed by the CPA. The Cost-Benefit Analysis Results section details the results of the cost-benefit analysis conducted using the considerations and variables identified in the previous section, identifying the net-present value (NPV) of investing in solar carport infrastructure in several scenarios. The Discussion section reviews the findings of the literature review, jurisdictional analysis, and cost-benefit analysis to assess whether investment in solar carport infrastructure is feasible or beneficial in the circumstances considered

for this report. The Recommendations section uses research findings to identify criteria for when the CPA should consider investing in solar carports. Finally, the Conclusion section summarizes the findings and recommendations. A comprehensive list of sources reviewed for this project can be found in the References section and further details and examples of information referenced throughout are contained in the Appendices.

RESEARCH PLAN

This research explored a comprehensive range of issues for the CPA to consider in making decisions about potentially investing in solar carports. These include the opportunities and constraints that may impact the CPA's ability to pursue this type of initiative, financial costs of investing in the infrastructure, the financial and social benefits associated with solar carports, and factors that may impact its feasibility.

To answer the research questions for this project, several approaches were used to gather information and conduct analysis. A literature review provided background information and key findings from previous research on topics related to investments in solar carports. A legal and administrative review, focused on the Calgary context, identifies both opportunities and constraints that may impact the feasibility of solar carport projects in Calgary. Using conclusions from these reviews, an initial assessment of existing surface lots managed by CPA identified which lots may be optimally situated for solar carport projects. Subsequently, a cost-benefit analysis was conducted for a hypothetical solar carport project on a CPA-managed surface lot that meets some of the initial criteria identified in the research.

Literature Review

A systematic review of relevant literature was conducted to collect, report, and analyse current knowledge, research, and case studies related to solar PV applications in surface parking lots. Potential costs and benefits and key considerations for solar carport projects can be identified by exploring how solar PV has or can be applied in surface parking lots. Although there are examples of residential and commercial installations worldwide, this literature review focused primarily on academic sources identified through the University of Victoria library online database. This also considers other academic research and grey literature to quantify the social benefit of offsetting greenhouse gas emissions and identify best practices for using social discount rates in cost-benefit analyses.

Legal and Administrative Review

A legal and administrative review of applicable programs, regulations, bylaws and policies in the Calgary context was undertaken to understand what factors may support or hinder solar carport projects. This included a review of any federal and provincial policies or programs that may provide incentives for municipal solar projects as well as the Municipal Government Act, Alberta Micro-Generation Regulation, and all relevant City Council policies, plans and programs including the Municipal Development Plan, Calgary Transportation Plan, Triple Bottom Line Policy, Sustainable Building Partnership Program, the Sustainable Building Policy, and the City's Climate Resiliency Strategy. The review also considered the City's Land Use Bylaw and applicable ENMAX Power Corporation restrictions and requirements because it is important for organizations to consider their municipal zoning and land use rules that allow for or restrict power generation, how a solar PV system will interact with the electricity grid, and how the electricity will be metered and sold to the system owner (Zaidi, 2009, pp. 114-117, 122-124).

Cost-Benefit Analysis

Building on findings from the literature, legal, and administrative reviews, this report includes a quantitative analysis using data and estimates from the literature and potential solar PV suppliers to determine the NPV of a feasible solar carport project by calculating the costs and benefits for each year of the investment.

Calculating the NPV will support the CPA and other organizations to make comparisons between present and future grid procedure electricity costs and the net costs of a solar PV project over its lifetime. Knowing the NPV enhances understanding of how long it may take for a project to become profitable under various conditions (Swift, 2013, p. 138). This analysis considers estimated and projected factors including initial capital investment, maintenance and operating costs, government incentives, the solar electricity that could be generated each year, and the value of electricity costs that could be avoided or sold back to the grid each year over the expected lifetime of a project.

In addition to using data and information drawn from the literature, legal, and administrative reviews, this research uses data and information obtained specifically for the purpose of this project. Specifically, the analysis uses site data for a selected parking lot obtained from the City of Calgary's Energy Management Office and cost estimates provided by ENMAX Solar. To forecast commodity costs, including pool price and wholesale electricity prices, the cost-benefit analysis utilizes existing forecasts prepared by third-party organizations including the Calgary-based EDC Associates Ltd. and the Alberta Electric System Operator (AESO).

The costs of negative externalities associated with greenhouse gas emissions including economic, environmental, and health costs are not typically considered as part of calculations analyzing the economic viability of investments in solar infrastructure (Branker, Pathak & Pearce, 2011, p. 4475). Although PV carports may be expensive and not economically viable for many organizations, public organizations have an obligation and greater capacity than many private organizations to take action to foster long-term common interests and promote a greener economy (Glemarec & Puppim de Oliveira, 2012, p. 212). Additionally, while private organizations may be most concerned with maximizing financial returns, government organizations exist to carry out public policy objectives that are not always focused on a financial end product (Public Sector Accounting Board, 2018, PS1100 Appendix A). In the context of government organizations with sustainability objectives, it makes sense to take externalities into account. Given Calgary's local commitment to reduce its carbon footprint and Canada's federal commitment to reduce greenhouse gas emissions, the cost-benefit analysis for this project will also consider the social cost of carbon and a solar carport's potential to displace greenhouse gas emissions to estimate and quantify the social benefit that could be gained from solar carport projects.

Limitations and Delimitations

The cost-benefit analysis for this research is based on a hypothetical solar carport project for a selected surface parking lot. Actual costs and benefits for any given project are likely to vary depending on a number of variables including the site chosen, the type of solar carport infrastructure selected, the size of the desired solar PV system, the cost of materials, and the solar provider. Although pursuing cost estimates for a real project would likely produce more accurate data for that specific project, solar carports are not currently part of the CPA's capital budget plans so it would be too costly and too time-consuming to pursue a more realistic solar carport project. This project does not identify the exact financial costs and benefits associated with any particular solar carport project, but the results of this literature review, jurisdictional review, and cost-benefit analysis together will identify the circumstances under which solar carport projects may be feasible so that the CPA may pursue detailed feasibility studies and costing with less uncertainty in future, should it choose to do so. This research also does not seek to compare costs or benefits for any other type of environmental infrastructure projects (e.g. such as rooftop PV) that the CPA may consider.

Additionally, it is currently very difficult to forecast electricity prices in Alberta for several reasons. Current electricity prices are considered unsustainably low (Thibault, 2016, p. 5) and historically, prices have been volatile (Government of Alberta, 2017b, para. 10). Alberta's electricity rates have been low in recent years due to the declining costs of natural gas, lower than forecasted demand resulting from a drop in industrial activity related to the decrease in oil prices, and an increase in supply due to excess generation capacity from the construction of new suppliers (Brown, 2018, p. 2; Livingston, 2018, p. 5). Over the last decade, the cost of electricity in Canada has increased faster than the rate of inflation (National Energy Board, 2017a, para. 1); however, in Alberta, where prices have been extremely volatile, the cost of electricity has fallen considerably (para. 3). Further, in accordance with the Government of Alberta's Climate Leadership Plan objectives to eliminate coal production and increase renewable energy generation, the province is currently transitioning from an energy-only market to include a capacity-market where generators are paid both for providing electricity and for making generation capacity available on demand. This is intended to support electrical system reliability (AESO, 2016, p. 4) and help to reduce price volatility (p. 27). To accomplish this, prices are expected to increase to incent supply, meet increasing demand, and replace end of life generation (Thibault, 2016, p. 5); however, the transition to a capacity market is not expected to increase rates beyond the level of increases that might have otherwise been expected (AESO, 2018, p. 2).

It is also not possible for this project to produce a cost-benefit analysis using the actual commodity costs applicable to City-owned sites. The City of Calgary entered into a 20-year long-term energy agreement with ENMAX Energy Corporation in 2005 and, unfortunately, the electricity rate paid by The City (and the CPA) to ENMAX is not public. Since the City's electricity rates are not publicly available and this agreement ends in 2025, it is difficult to accurately forecast what wholesale rate of electricity the CPA may pay or receive as compensation for micro-generation in the future. As a result, the data used to conduct the cost-benefit analysis for this project is based on forecasted market rates and will not necessarily

reflect the actual benefits or value that the CPA may receive for offsetting its consumption or selling energy to the grid. This information is, however, available to The City of Calgary's Energy Management Office and that team would be able to support the CPA to conduct a detailed feasibility study for any specific solar project that the CPA may choose to pursue in the future. Further, The City requires that any actual solar projects pursued by City entities be routed through the Energy Management Office, although the resources prepared for this research may be used and updated to conduct more realistic cost-benefit analyses in the future.

Further, this report uses carbon price estimates to quantify the benefits of offsetting carbon emissions by investing in renewable energy infrastructure. These estimates are based on the anticipated marginal cost of carbon abatement necessary to achieve Canada's Paris Agreement commitments to limit global warming. Substituting solar for coal not only reduces carbon emissions, but also reduces other types of harmful emissions and pollution that affect air quality, the environment, and human health. Although important, a valuation of these benefits is beyond the scope of this analysis.

LITERATURE REVIEW

This literature review explores findings in the academic literature relevant to solar PV applications in surface parking lots to build an understanding of costs, benefits, and factors that impact the feasibility of solar carport projects. This includes design considerations, factors that impact costs and cost-effectiveness and the potential for this infrastructure to create a revenue source, offset energy costs, and reduce greenhouse gas emissions. Reduction in carbon emissions is important because of the social cost of carbon to society, which researchers have sought to quantify in relation to Canada's greenhouse gas reduction targets. Further, the literature explores additional benefits related to solar carports, such as shading benefits associated with covering the expansive pavement in surface parking lots, and the growing potential for solar carports to be part of electric vehicle (EV) charging solutions.

Additionally, anticipating the cost-benefit analysis component of this project, this literature review includes an overview of the literature related to social discount rates to understand how public organizations should best evaluate the long-term costs and benefits of this kind of environmental investment.

Solar Infrastructure

Solar PV Applications in Surface Parking Lots

Solar conversion, the process whereby PV cells capture solar energy and convert it to electricity directly, provides the largest potential renewable source of energy to meet the world's needs (Smil, 2012, pp. 440-441). Solar PV is also considered preferable to wind as a renewable energy source to meet increasing demand for electricity because it can be implemented in a distributed model (Nunes, Figueiredo & Brito, 2016, p. 680). Although rooftop panels are the most common urban solar application, solar carports and canopies are increasingly being explored as an opportunity to generate a significant amount of renewable electricity in surface parking lots (Alghamdi, Bajah & Wu, 2017, pp. 2, 20). For example, it is estimated that if 200 million parking spaces in the US were covered by solar panels, those solar panels could produce approximately three billion kWh per day, comprising nearly one-quarter of electricity currently produced in the United States (Erickson & Jennings, 2017, pp. 54-55). To date, there is no comparable analysis of parking lot solar potential in Canada.

Two main types of solar infrastructure could be applied in surface parking lots: solar carports and canopies. Solar carports, which are oriented to parking spaces, provide shade, shield against the elements (Neumann, Schar & Baumgartner, 2011, p. 642), typically have a back-to-back structure (Alghamdi, Bajah & Wu, 2017, p. 11) and may cover rows, entire lots, or segments of lots (Nunes, Figueiredo & Brito, 2016, p. 681). Solar infrastructure does not typically cover the entire physical footprint of dedicated parking areas because space is needed to install and maintain the infrastructure and to allow for vehicle access and maneuvering (Alghamdi, Bajah & Wu, 2017, p. 12). In terms of size, a typical solar carport covers 17 m² of ground space and has a total roof area of 18.1 m² (Alghamdi, Bajah & Wu, 2017, p. 12).

Although research conducted in Saudi Arabia has found that solar carports are optimally south facing and set to a 20-degree angle (p. 12), the Solar Energy Society of Alberta states that a solar modules will be the most productive when they are perpendicular to the sun and should be set at an angle equivalent to a site's latitude, although the ideal tilt changes from winter to summer (2018, para. 17). Consistent with this, a study in Edmonton, Alberta found that at 53 degrees latitude, the optimal tilt angle was 53 degrees (Matthews, 2016, p. 6); however, Alghamdi, Bajah and Wu point out that the design of solar carport structures (usually a back-to-back structure covering two rows of vehicles) may affect the angle that is chosen and that a 20 degree angle is sufficient to allow rain, dust and debris to fall off, ensuring less obstruction of the PV surface (2017, pp. 11-12). In the Canadian context, snow is also a consideration and a greater tilt means that snow is more likely to slide off without being cleared manually (Solar Energy Society of Alberta, 2015, para. 6).

As an alternative to solar carports, solar canopies are composed of solar panels that rest on cables drawn across a parking lot. Solar canopies can cover the entire area of a parking lot, require less materials, and may have better solar potential because they do not need to be oriented to parking spaces; however, they do not provide the same shading benefits as carports (Neumann, Schar & Baumgartner, 2011, p. 642). Both solar carports and solar canopies may also help to enhance the visual appeal of conventional surface lots by functioning as public art in spaces that are generally unappealing. Mukhija and Shoup (2006) describe solar canopies in Southern California that have artistic-looking trellises and cast patterns of shade on the pavement (pp. 302-304).

Cost Considerations

Despite its potential, solar PV has generally been too expensive on an unsubsidized basis to compete with conventional energy generation options (Bazilian et al., 2013, pp. 330-331; Smil, 2012, pp. 440-441; Branker, Pathak & Pearce, 2011, p. 4475; Row et al., 2011, pp. 30-33; Timilsina, Kurdgelashvili & Narbel, 2012, pp. 450-454). High capital costs have limited widespread adoption to date, but PV cells have become increasingly affordable over the past 30 years as the technology has improved and become more cost effective. Despite this, investments in solar projects are still limited due to a lack of funding, legal support, and political will (Glemarec & Puppim de Oliveira, 2012, p. 209). Additionally, environmental considerations, like the social cost of carbon, are not typically included in economic analysis of potential projects (p. 209).

Solar carports are more expensive than typical ground mounted solar PV systems because of their unique specifications (Alghamdi, Bajah & Wu, 2017, pp. 18-19). For example, solar carports must be resistant to vehicular impact and must be tall enough for vehicles to park underneath. In northern climates, panels must also be resilient to hail and cold temperatures; considerations that are not applicable in warmer locations; however, solar modules are made with tempered glass that is rated to withstand one inch hail at 88 kph and are tilted so that they rarely experience perpendicular hits, so hail is generally not a concern (Solar Energy Society of Alberta, 2018, para. 22).

In addition to the upfront investment in capital costs, operating and maintenance costs for solar infrastructure increase over the lifetime of a system. Inverters, which convert solar energy into electrical power, must be replaced every ten years (Alghamdi, Bajah & Wu, 2017, p. 17; Branker, Pathak & Pearce, 2011, p. 4476) and occasionally, systems may require cleaning and electrical system repairs (Branker, Pathak & Pearce, 2011, p. 4476). In the Canadian context, snow can obstruct solar panels and reduce energy production in the winter months; however, this occurs during the time of year where production is at its lowest anyway and the costs incurred to clear snow may not be worth the benefit of maximizing production potential, especially given that it can be dangerous to do so (Solar Energy Society of Alberta, 2018, para. 21). Consistent with this, Matthews found that the difference in output resulting from snow clearing in Edmonton is minimal (2016, p. 7). Southern Alberta also experiences frequent chinook winds which cause temperatures to rise and snow to melt rapidly (CBC, 2017, paras. 4-5). This phenomenon may mean snow clearing is even less necessary in the Calgary context.

Given these considerations and few maintenance costs, solar carports require relatively low annual operating costs after the initial costs for installation and are scalable, so investments can be made incrementally over time as funds become available (Row et al., 2011, pp. 43-44).

The costs and returns for solar carports varies by location and local economy. For example, the solar resource available will vary by location (Branker, Pathak & Pearce, 2011, p. 4478) and returns are dependent on the cost of electricity (Robinson, Brase, Griswold, Jackson & Erickson, 2014, 7364). Importantly, although solar carports can be constructed anywhere, not all parking lots will receive sufficient solar radiation for PV electricity generation and therefore only some locations will be ideal sites for this type of investment (Neumann, Schar & Baumgartner, 2011, p. 645). Additionally, while parking lots of all sizes may be suitable (Neumann, Schar & Baumgartner, 2011, p. 645), there are economies of scale for larger projects (Erickson & Jennings, 2017, p. 55).

Specific expenses for solar carports include the solar PV system, design and installation, and administrative costs including insurance and grid connections (Branker, Pathak & Pearce, 2011, p. 4475). Incentives should also be included in determining the specific costs or benefits that should be considered (Branker, Pathak & Pearce, 2011, p. 4478). For example, solar projects may be more economical for agencies in jurisdictions that offer subsidies.

Investments in solar PV provide a return on investment in the form of energy savings and energy sales to the grid (Row et al., 2011, p. 44). A system composed of 7 m² of PV panels, operating at peak maximum capacity (kWp) will produce approximately 1 kWh of electricity (Nunes, Figueiredo & Brito, 2016, p. 681). An average parking space can be covered with PV panels that will generate approximately 1.7 to 2.1 kWh at peak capacity. A parking space with 2 kWp will yield between 1,900 to 3,400 kWh annually, depending on the region. Payback on investment in solar carport infrastructure is estimated to range between seven to 16 years, depending on the size of a project, solar resource available, and financial conditions (e.g. electricity price) (Alghamdi, Bajah & Wu, 2017, pp. 16-17; Figueiredo, Nunes & Brito, 2017, pp. 1193-1195).

Manufacturers typically guarantee that solar PV panels will last 25 years (Alghamdi, Bajah & Wu, 2017, p. 16), however, generally panels can be expected to last more than 30 years (Branker, Pathak & Pearce, 2011, p. 4475). Over its lifetime, a solar PV system will gradually degrade over time. This is important because energy output depends on the assumed degradation rate of panels. Conservative estimates, including manufacturer warranties, assume that panels degrade at a rate of one per cent per year (Alghamdi, Bajah & Wu, 2017, p. 17; Branker, Pathak & Pearce, 2011, p. 4476). However, some estimate that a degradation rate of 0.2 to 0.5 per cent is more realistic (Branker, Pathak & Pearce, 2011, p. 4476). If PV systems have capacity losses at a fixed rate of one per cent per year over the lifetime of the system (Alghamdi, Bajah & Wu, 2017, p. 17). For example, a solar system that generates 66.2 GWh in year one will produce 52.0 GWh in year 25.

Potential to Generate Renewable Electricity

Generating Renewable Energy for Site or Community Needs

Solar PV in parking lots provides an alternative means to generate electricity to meet increasing local demand, supplementing both base load and peak power needs for buildings, signage and other municipal needs (Alghamdi, Bajah & Wu, 2017, pp. 2-3; Golden, 2006, p. 20; Golden, Carlson, Kaloush & Phelan, 2007, p. 882; Rowlands, 2005, p. 833). Analysis in a residential community in Calgary found that solar energy has the potential to support 67 to 100 per cent of community energy needs during summer months (Hassan, Rahman, Haque & Ali, 2011, p. 7). Electricity generated from solar PV panels can support localized demand for energy or be exported to the electricity grid (Alghamdi, Bajah & Wu, 2017, p. 20; Rowlands, 2005, p. 833). Previous researchers have explored storing surplus energy produced for use during peak hours (i.e. not exporting surplus to the grid) and have found that it is not economically feasible (Figueiredo, Nunes & Brito, 2017, p. 1195).

Offsetting Carbon Emissions

Solar PV in parking lots also provides a way to help communities achieve low carbon targets by offsetting non-renewable energy use to reduce greenhouse gas emissions and the environmental footprint associated with parking lots and low-occupancy vehicle use (Alghamdi, Bajah & Wu, 2017, pp. 2-19; Erickson & Jennings, 2017, pp. 48-49). The ratio of greenhouse gases per unit of electricity generated (the greenhouse gas intensity of electricity generation) in Alberta, which relies primarily on fossil fuels, is the highest in the country at 790 grams of CO₂ per kWh (National Energy Board, 2017b, Figure 4). Renewable energy sources, which do not produce direct CO₂ emissions in generating electricity, do have life-cycle emissions associated with manufacturing, installation, maintenance and other generation-related activities; however, solar panels themselves are carbon neutral after two years (Nunes, Figueiredo & Brito, 2016, p. 681).

The Marginal Cost of Abatement

The social cost of carbon (SCC) is understood as the net present value of the incremental damages caused by increases in carbon emissions in a given year (Newbold et al., 2010, p. 2; Nordhaus, 2017, p. 1518). This number, sometimes called an implicit or shadow price on carbon, quantifies negative externalities of carbon emissions including effects on human health, agricultural productivity, and costs to property and infrastructure due to extreme weather and sea level rise (Newbold et al., 2010, p. 2; Tol, 2011, p. 427, 435). SCC estimates increase annually because the marginal damage caused by emissions changes over time (Nordhaus, 2017, p. 1521).

Subsidies and government investments in near-zero emissions technology and infrastructure that can influence carbon emissions affect a small percentage of total emissions and are not the same as carbon pricing, however, the implicit price of these investments can be used to estimate the cost to achieve the same level of emission reductions as a package of alternative policies (Jaccard, Hein & Vass, 2016, pp. 1-2). It is beneficial to use carbon price estimates in cost-benefit analyses because, if an investment can reduce emissions at a cost less than the cost of carbon emissions, the investment can improve the efficiency of resource allocation in society (Heyes, Morgan & Rivers, 2013, p. S68; Newbold et al., 2010, p. 2). Use of a carbon price in cost-benefit analysis is an important component of demonstrating the value of investments in initiatives to enhance environmental sustainability (p. S70).

Federal departments and agencies have been using SCC values to conduct regulatory impact assessments that involve greenhouse gas emissions since 2011 (Environment and Climate Change Canada, 2016, p. 2). The SCC values used by the Government of Canada were adopted based on research and analysis conducted by the United States Interagency Working Group on the Social Cost of Carbon in 2010 and were updated in 2013 (pp. 13-15); however, research suggests that the Government of Canada's current SCC estimate of \$54.50/tonne by 2030 (in 2012 dollars) (Environment and Climate Change Canada, 2016, pp. 26-27), may be too low. The integrated assessment models used to calculate SCC estimates exclude or underestimate the potential for catastrophic disasters and impacts that are unknown or difficult to measure, such as climate change effects on biodiversity (Heyes, Morgan & Rivers, 2013, pp. S67-S68, S71; Tol, 2011, pp. 427, 436). Even the Government of Canada suggests using a higher SCC value for sensitivity analysis (Environment and Climate Change Canada, 2016, pp. 26-27), which Heyes, Morgan and Rivers agree would better reflect the total costs of emissions to society (2013, p. S71).

Further, researchers project that the federal Pan-Canadian Framework on Clean Growth and Climate Change will fall short of Canada's Paris Agreement commitments without policies that adequately value the cost of carbon emissions (Rissman et al., 2018, pp. 6-14; Sawyer & Bataille, 2017, p. 1) and that the SCC would be more effective if construed as the marginal cost of abatement required to achieve Canada's emissions reduction targets, consistent with the practice adopted in the U.K. (Heyes, Morgan & Rivers, 2013, pp. S76-77).

To achieve its Paris Agreement commitment to reduce Canada's GHG emissions to 30% below 2005 levels by 2030, Jaccard, Hein and Vass (2016) suggest that a Canada-wide emissions

price would need to start at \$30/tonne of CO₂ and rise annually to \$200/tonne in 2030 (in 2015 dollars) (p. 32). Sawyer and Bataille (2017) estimate that the price of carbon may need to be even higher at \$220/tonne (in 2016 dollars) by 2030 to achieve Canada’s goal to reduce greenhouse gas emissions (p. 5). However, it is possible that carbon pricing at even this level would be sufficient to limit warming in accordance with Paris Agreement targets. A recent report from the Intergovernmental Panel on Climate Change (2018) warned that, based on countries’ current NDC pledges, warming will exceed 1.5 degrees Celsius above pre-industrial levels with “irreversible climate impacts” (p. 6).

Table 1 compares various estimates for a 2030 carbon price in 2018 dollars, calculated using the Bank of Canada’s Inflation Calculator.

Table 1

Estimated carbon prices for 2030 per tonne of CO₂ emissions (in 2018 CDN dollars).

| | Federal (95 percentile estimate) (2016) | Jaccard, Hein & Vass (2016) | Sawyer & Bataille (2017) |
|--|---|-----------------------------|--------------------------|
| Federal (base central estimate) (2016) | \$60.24 | \$211.00 | \$229.22 |

Shading Benefits

As shading structures, solar carports can help vehicles to stay cool in warm weather, improving comfort for vehicle occupants (Alghamdi, Bajah & Wu, 2017, p. 19; Nunes, Figueiredo & Brito, 2016, p. 681; Robinson et al., 2014, 7362) and reduce the need for air conditioning and additional non-renewable energy consumption (Alghamdi, Bajah & Wu, 2017, p. 2, 19; Erickson & Jennings, 2017, p. 48). Additionally, research demonstrates that there is demand for shaded parking in surface lots, meaning that parking providers may be able to charge higher prices for this kind of amenity (Erickson & Jennings, 2017, p. 48).

Solar carports have also been identified as a means of mitigating the urban heat island effect. The urban heat island effect has been demonstrated in urban areas that have significantly higher temperatures, caused by reduced vegetation and an increase in paved surfaces, causing increasing energy use and increased levels and risk of illness due to heat stress (Mohajerani, Bakaric & Jeffrey-Bailey, 2017, pp. 523-524). The shade provided by solar carports, especially for large volume parking lots in school and retail parking lots, has been shown to reducing the need for mechanical cooling in communities (Golden, 2006, p. 19; Golden, Carlson, Kaloush & Phelan, 2007, p. 882). In addressing effects, solar carports have been shown to have more immediate benefits and use less water than urban forest projects (Golden, 2006, p. 20; Golden, Carlson, Kaloush & Phelan, 2007, p. 882).

EV Charging Potential

Additionally, by covering parking lots with solar panels and adding EV charging infrastructure, cities can support consumers to transition to EVs by increasing the availability of EV charging in long-stay parking areas, contribute to reduced carbon emissions (Erickson &

Jennings, 2017, p. 48) and help meet increasing demand for electricity as a result of EV charging and other electricity needs (Alghamdi, Bajah & Wu, 2017, p. 2; Neumann, Schar & Baumgartner, 2011, p. 648; Robinson et al., 2014, p. 7358). Robinson et al. (2014) anticipates that a 30 per cent increase in EV use could result in a 150 per cent increase in peak load electricity consumption (pp. 7366-7367). Solar powered charging stations in existing parking lots could help to meet these peak load requirements and help to ensure that EVs are free of both direct and indirect GHG emissions or pollutants (Nunes, Figueiredo & Brito, 2016, p. 681). The extent of existing long-stay parking lots also presents many places and opportunities for solar charging while parking, which adds convenience for EV owners (Nunes, Figueiredo & Brito, 2016, p. 681). It also presents opportunities for charging entire fleets of vehicles as companies transition to EVs (Nunes, Figueiredo & Brito, 2016, p. 683). By supporting increased use of EVs, solar carports could then further benefit greenhouse gas reduction targets by decreasing drivers' reliance on fossil fuels and reducing air pollution. While solar carports that incorporate solar charging come with additional costs due to charging stations and control hardware, these additional costs could be offset by charging for EV charging (Nunes, Figueiredo & Brito, 2016, p. 684). Notably, there are benefits to solar carports even without EV charging capabilities and simple carports are much less expensive (Nunes, Figueiredo & Brito, 2016, p. 684).

Social Discount Rates

A further consideration necessary to inform the cost-benefit analysis for this project is the social discount rate. The discount rate used by a public-sector organization can be understood as the minimum rate of return that the organization requires from an investment (Creedy & Passi, 2018, p. 139). Generally, a discount rate used in cost-benefit analyses adjusts the value of money over time to express expected future monetary quantities in terms of their worth today (Alberta Transportation, 2017, p. v).

On the basis that public sector investments compete with the private sector and may come at the expense of private sector investment and consumption, the Treasury Board of Canada recommends a discount rate of eight to ten per cent (Boardman, Moore & Vining, 2010, p. 327). However, in the context of population growth, depletion of non-renewable resources, and climate change, the practice of discounting future benefits may create a bias against investing in sustainability initiatives, making them almost impossible to justify (Gagné, 2014, p. 3; Boardman, Moore & Vining, 2010, p. 334; Creedy & Passi, 2018, p. 139). As a result, a social discount rate may be used to value future costs and benefits of environmental investments (p.3). A social discount rate is based on society's willingness to make investments now, foregoing current benefits to generate future benefits (Boardman, Moore & Vining, 2010, p. 326). The practice of discounting future benefits assumes that future generations will be better off than the current one (Gagné, 2014, p. 3) and implies that events in the far future are less important than more proximate events (Weitzman, 1998, p. 201), but for environmental investments that reduce GHG emissions, the mitigation costs incurred in the present are expected to result in benefits that will last for centuries (Arrow et al., 2012, p. 1). Additionally, the public sector can use a lower discount rate than the private sector because the public sector can be more

patient to receive a return on investment (Alberta Transportation, 2017, p. 29). Consistent with this, Alberta Transportation's practice is to use a discount rate of four per cent (p. 23),

Due to uncertainty about future growth in per capita consumption, there is a strong theoretical basis for using declining social discount rates in intergenerational contexts that have long time horizons (Arrow et al., 2012, p. 14; Boardman, Moore & Vining, 2010, p. 338; Weitzman, 1998, p. 207). Boardman, Moore and Vining recommend the following declining discount rates for cost-benefit analyses:

- 3.5 per cent from years one to 50;
- 2.5 per cent from years 51 to 100;
- 2.0 per cent from years 101 to 200; and
- 1.5 per cent years 200 plus (2010, p. 335).

For a 400-year investment, the above declining discount rates are equivalent to applying a single constant rate of 2.0 per cent over the 400 year period (p. 335). For sensitivity analysis, they suggest using a low social discount rate of 2.5 per cent and a high social discount rate of 7.0 per cent (p. 333). However, there are also arguments that a social discount rate should be negative if it is believed that future generations will be worse off than the current one (i.e. due to the negative impacts of climate change), or zero if future generations are expected to be equally well off (Gagné, 2014, p. 5).

LEGAL AND ADMINISTRATIVE REVIEW

Although the literature elucidates the potential benefits of solar carports, the possibility of investing in solar carports may be supported or limited based on the local policy environment. A review of applicable regulations, policies, programs, and rules in the Calgary context is necessary to understand the full range of opportunities and barriers for CPA investment in solar carports. This information is essential to understanding if solar carport projects are feasible and can support rationales for capital funding requests.

First, this legal and administrative review considers provincial regulation governing micro-generation, and electricity pricing factors, including electricity market design that may impact the potential benefits associated with solar carports.

After establishing the context for micro-generation, this research turns to City of Calgary policies that may support or limit solar carport projects including consideration of City policies and strategies related to environmental sustainability, carbon abatement, and renewable energy initiatives as well as a review of how the Calgary Land Use Bylaw may impact the feasibility of solar carport projects in CPA-managed surface lots. Additionally, this scan looks at rules created by ENMAX Power Corporation to identify areas where micro-generators are permitted to export energy to Calgary's power grid. Based on technical and land use constraints, it is possible to identify CPA surface lots where solar carport projects may be most feasible (see Appendix C).

Finally, this legal and administrative review explores potential funding opportunities to support or subsidize capital investment in solar carport infrastructure. This report looks to government and third-party sources of funding to identify how the total cost of a solar carport investment could be reduced for the CPA.

Alberta Micro-Generation Regulation

Micro-generation in Alberta is governed by the Alberta Micro-Generation Regulation. Renewable energy projects in Alberta that are 5 MW or less and are intended to meet all or a portion of the customer's total energy consumption at the customer's site or aggregated sites are considered micro-generation projects (Micro-Generation Regulation, 2008, pp. 1-3). Customers can generate renewable electricity for on-site use and can be compensated for supplying energy to the province's electric system. Alberta uses net billing to compensate micro-generators, which means that customers receive a net charge or credit based on their net use of electricity. Small micro-generators (that have a nameplate capacity of less than 150 kW) receive credit at the rate for electricity supplied to the site (i.e. the wholesale consumer commodity rate) whereas large micro-generators (that have a nameplate capacity of between 150 kW and 5 MW) receive credit at the electricity pool price (p. 8).

In accordance with these policies, the CPA may directly benefit from renewable energy produced by solar carports in several ways. First, electricity generated may be consumed onsite to offset the cost of electricity that would otherwise be drawn from the grid. This is the scenario whereby the CPA may experience the greatest value, as onsite consumption offsets both commodity and delivery costs (including distribution and transmission charges). Ideally, solar

carports would be installed at locations where all the energy produced could be consumed onsite; however, due to the location of most City surface lots managed by the CPA, solar carports would almost always produce an annual surplus of renewable energy, depending on the size of the installation and the amount of electricity consumed onsite.

Factors Impacting Electricity Rates

As detailed in the section on research limitations, it is difficult to forecast electricity rates in Alberta or what rates will be applicable to the City of Calgary over the long term. The City of Calgary's 20-year long term energy agreement with ENMAX and upcoming changes to Alberta's electricity market implemented under the province's Climate leadership Plan will impact electricity pricing and the rates that micro-generators may be compensated for electricity that they produce. Anticipating that electricity prices may fluctuate as Alberta transitions to include a capacity market, the provincial government has capped the consumer wholesale electricity price at 6.8 cents/kWh (Government of Alberta, 2017b, paras. 4-10). The price cap, which took effect June 1, 2017 and will be in effect until May 31, 2021, means that consumers on the regulated rate option will pay the market rate or the government's cap rate, whichever is lower (para. 5).

Municipal Policy, Strategy and Bylaws

Municipal Development Plan and Calgary Transportation Plan

The Municipal Development Plan (MDP), a statutory plan developed in accordance with the Alberta Municipal Government Act, sets out Calgary's vision and plan for how it will grow and develop over the next 30 to 60 years. The MDP is focused on building "a more sustainable city" (2017, p. 14) and sets out sustainability principles for land use and mobility, including a mandate for The City to utilize green infrastructure and buildings (p. 18). In particular, the plan includes a goal to conserve, protect, and restore the environment by creating opportunities to generate renewable energy and reducing the city's ecological footprint (pp. 63-64); however, the plan also notes that, "in the case of greenhouse gas emission reductions, Calgary may need financial assistance to implement a full set of successful initiatives" (p. 30), recognizing that investments in infrastructure and technology to support environmental sustainability are expensive and likely require support from other levels of government.

The Calgary Transportation Plan, which sets out goals and objectives specific to transportation infrastructure in alignment with the MDP, includes a goal to "advance environmental sustainability" (2012, p. 10). The plan's parking policies, which recognize that parking uses land in inherently unsustainable ways, set out objectives to manage parking to reduce the city's environmental footprint and integrate green infrastructure in parking facilities (pp. 58-59).

Calgary's Climate Resiliency Strategy

The City of Calgary's Climate Resiliency Strategy (2018) recognizes the impact that greenhouse gas emissions have on the city's environment and economy, conveying that reducing

emissions will result in cost-savings for Calgarians and establishing a high-level commitment to mitigate and manage climate risks and achieve emissions reductions targets (pp. 5-9). The City's Climate Action Mitigation Plan, established within the strategy, outlines means of reducing emissions through better energy management, implementing renewable energy projects and supporting a low carbon economy (p. 9). The City's Environmental & Safety Management business unit is tasked with enabling the implementation of onsite renewable and low-carbon energy systems, including implementation of solar PV systems (p. 39).

Calgary's Land Use Bylaw

The City of Calgary's Land Use Bylaw regulates how land may be developed in Calgary. The city is divided in land use districts (zones) which each have prescribed permitted or discretionary uses. Both parking and power generation are defined uses in the Land Use Bylaw. Land use designations for parcels that include parking managed by the CPA are listed in the CPA's annual Land Use Summary Report (2018, p. 8).

"Parking Lot – Grade" refers to a use where vehicles are parked at grade for a short duration, independent of any other use (Calgary Land Use Bylaw, 2018, s. 252) while "Parking Lot – Grade (temporary)" may be approved on a temporary basis for no more than three years at a time (s. 252.1). For many land use districts, parking is not allowed as a specific use for a site but may be required in relation to other permitted or discretionary uses. Surface lots that are approved as a temporary land use may not be suitable for solar carports because the continued use of the site as a parking lot is subject to the approval of the City's Development Authority and is not guaranteed. As a result, the lot may not exist long enough for the CPA or City to reap the full benefits of a solar carport investment (e.g. Lot 75 is a temporary use). Several CPA managed surface lots are on parcels of land that are subject to a Direct Control Bylaw, which means that at-grade parking or a use that requires on-site motor vehicle parking has been specifically approved as an allowable use for that particular property.

The Land Use Bylaw also provides for small, medium and large power generation facilities. The most applicable use for this project is "Power Generation Facility – Small", a use where electrical power is generated, and the total power generation capacity is between 10 watts and 1.0 megawatts (s.266). Solar carports may only be possible at sites where power generation is a permitted or discretionary use. Based on the current land use designations for CPA managed lots, small power generation facilities are either a permitted or discretionary use for most sites, with some exceptions (e.g. Lot 74 and Direct Control districts). For land use districts where power generation is not a permitted or discretionary use, solar carports may only be possible if a land use amendment is approved by City Council (e.g. for Direct Control districts). Land use amendments require a public hearing in accordance with the Municipal Government Act (s. 17).

Other Applicable Policies, Rules, and Regulations

Secondary Network Restrictions

Although most CPA managed lots are eligible to have small power generation facilities like solar carports under the Land Use Bylaw, micro-generation that involves selling power to

the grid is not currently possible at all sites. ENMAX Power has four Secondary Networks throughout Calgary which provide multiple parallel sources of power to customers in these areas to ensure minimal disruptions in power (ENMAX Power, n.d., paras. 1-2). Due to the design of these networks, customers are not permitted to export power to the grid within the boundaries of these networks.

Although it is not possible at present to connect renewable energy generators to the grid within secondary networks in Calgary, ENMAX is currently exploring technology that will allow customers to generate renewable energy in the downtown core (Ward, 2018, paras. 4-11). Commercial technology applications may be available after 2022 (para. 12).

In the current context, the CPA is primarily affected by the downtown secondary network boundary, having few lots outside of the inner-city; however, private parking providers and other City business units that provide parking, such as Calgary Transit, Recreation, and Parks, may be affected by the secondary networks near Chinook Centre, Westbrook Mall, and North Hill Mall. Unfortunately, most CPA-managed surface lots fall within the downtown secondary network boundary and due to low on-site energy consumption would likely need to export to the grid, limiting the number of sites that where solar carports are reasonably possible. Based on the network boundaries, only ten lots could technically export to the grid.

An overview of characteristics for CPA-managed surface lots that fall outside of the ENMAX secondary network is provided in Appendix C.

Subsidy Programs

Overview

Despite commitments from all levels of government to reduce emissions and invest in renewable energy infrastructure, there are few current programs that provide support for municipalities or projects of this type and scope. Federal government initiatives primarily support large, utility-scale generation projects and the development and commercial application of new technologies. The Government of Alberta has several subsidy programs targeted to support renewables for residential, commercial, non-profit, agriculture and Indigenous community applications, but only one applicable to municipalities called the Alberta Municipal Solar Program (AMSP). The Federation of Canadian Municipalities (FCM) also provides funding for municipalities to obtain financial support for environmental sustainability initiatives. The City may be eligible to receive funding for solar carport projects through one or both of these programs.

In Calgary, a limited amount of centralized funding for renewable energy infrastructure has typically been allocated through the City's capital budget to the Environment & Safety Management unit; however, these funds are directed toward the most cost-effective projects identified across the corporation.

Alberta Municipal Solar Program

The AMSP, a program created by the Government of Alberta to support implementation of Alberta's Climate Leadership Plan, offers funding for municipalities to install grid-connected solar PV systems that are greater than two kilowatts in installation capacity and are compliant with the Alberta Micro-Generation Regulation on municipal land (Municipal Climate Action Centre, 2018, p. 2). The AMSP provides a rebate per watt of total installed capacity that varies based on system size and smaller systems receive a larger rebate per watt of installed capacity. Systems with a total installed capacity of 150 kW to less than two MW may be eligible for a rebate of \$0.60/W up to 25 per cent of eligible expenses (p. 3); however, funding is available on a first come, first served basis, municipalities can only apply after a project is confirmed, funding is only received after a project has been completed, and municipalities are subject to a \$1.5 million funding cap (pp. 4-6). Eligible expenses for AMSP funding include the costs for the solar PV equipment, design, procurement, construction, permits and approvals, and inspection costs (pp. 3-4). Ineligible expenses include GST, operating and maintenance costs, and the cost of City employee hours dedicated to working on the project or preparing the funding application (p. 4). The City of Calgary's Energy Management Office has previously received funding for City solar PV projects and it is likely that solar carport projects would be eligible for this funding; however, with multiple business units pursuing energy efficiency and emissions reductions initiatives related to the Climate Action Mitigation Plan, the Energy Management Office will likely prioritize funding applications for those projects that will provide the best value to The City.

FCM Green Municipal Fund

The Federation of Canadian Municipalities (FCM) Green Municipal Fund provides support to municipalities in the form of low-interest loans (for 80 per cent of eligible project costs, up to \$5 million) and grants (15 per cent of the loan) for capital projects that reduce greenhouse gas emissions (FCM, 2018a, paras.1-10). The City may be eligible for support from the Green Municipal Fund; however, it is not clear if solar carport projects would be considered eligible initiatives. FCM funds both new construction and retrofit projects (FCM, 2018b, paras. 1-20). New construction projects designed for net zero energy performance such as PV systems are eligible for funding, but it is not clear if infrastructure built at existing surface parking sites may be considered new buildings.

COST-BENEFIT ANALYSIS

This section identifies and explains the inputs used in the cost-benefit analysis for this project. Specifically, it identifies a location based on factors identified in the jurisdictional scan and literature review and details the factors, data, assumptions, and estimates that inform the calculations to obtain NPVs for a variety of scenarios and sensitivity analyses. Based on features of the chosen site, Lot 59 in Sunnyside, ENMAX Solar produced metrics for a proposed solar PV system and a solar provider produced cost estimates for materials and installation of solar carports based on those system metrics and site characteristics which form the basis of the cost side of the equation to calculate NPVs. Also considered are projected maintenance and operations costs over the lifetime of the project as well as funding that may be available to reduce the initial costs of the project.

The cost-benefit analysis for this project further considers potential benefits associated with producing and consuming or selling renewable energy to the grid in accordance with the province's regulatory framework for micro-generation and using forecasted consumer electricity rates and pool prices that would impact cost savings and revenues for the proposed solar carport project. Additionally, a marginal cost of carbon abatement, derived from the literature, is identified to support an additional layer of analysis and factor in broader societal benefits that may result from investments in renewable energy infrastructure.

Hypothetical Solar Carport Project

Lot 59 Sunnyside

Based on the literature review and jurisdictional scan, the surface parking lot selected for this cost-benefit analysis of a hypothetical solar carport project is Lot 59, located at 200 Memorial Drive N.W. across from Prince's Island Park. Lot 59 is a City-owned parking lot stewarded by Calgary Parks in the City's Community Services department and is managed by the CPA. Analysis of a hypothetical solar carport project for Lot 59 was undertaken with permission from Calgary Parks and using site data provided by the City of Calgary's Energy Management Office. It has 179 parking spaces, including 10 accessible stalls. Satellite images of Lot 59 are contained in Appendix D.

The site that Lot 59 is located on has several features that make it a possible location for solar carports. Under the Land Use Bylaw, the site for Lot 59 is zoned S-R Special Purpose - Recreation and S-UN Special Purpose – Urban Nature, which means that the parking available on this site is intended to support public access to Prince's Island Park and recreational facilities and is unlikely to be repurposed for another land use in the near future (i.e. at-grade parking is not a permitted or discretionary use for this site). Small power generation facilities are a permitted use under the S-R designation and a discretionary use under the S-UN designation, meaning that a solar carport project on this site could proceed with approval from the City's Development Authority and would not require a land use amendment.

Additionally, Lot 59's location on the north side of the Bow River and Prince's Island Park means that it has good unobstructed sunlight from the south. It is also located outside of ENMAX's secondary network, which means that the site is eligible for grid-connection. As a surface parking lot with few energy needs other than lighting, energy consumption for Lot 59 is limited. ParkPlus machines that accept payment are already powered by solar panels that produce energy stored in batteries. Site data for Lot 59 shows that it consumed just 4,231 KWh in 2017 and incurred \$722.38 in transmission and delivery costs (including GST) last year.

Proposed PV System Information

Based on the site data for Lot 59, ENMAX Solar, a division of a wholly-owned subsidiary of the City of Calgary, designed a solar carport system and facilitated cost estimates for this analysis.

Although a larger solar PV system would likely be more cost-efficient, the hypothetical solar PV system designed for this analysis does not cover all 179 stalls in Lot 59 because no other lot that may be suitable for solar carports is that large and it is unlikely that the CPA would experience those cost efficiencies on a per stall basis for any existing surface parking lot other than Lot 59. As a result, the proposed solar carport system designed by ENMAX Solar for this analysis would cover 76 stalls in the centre row of the lot. The nameplate capacity for the proposed system is 160.0 kW and it would be expected to generate 193,927 kWh of renewable energy in its first year.

Although solar PV systems may be expected to last 30 to 40 years (Branker, Pathak & Pearce, 2011, p. 4475), the manufacturer warranty for the system quoted for this project is 25 years, consistent with the manufacturer guarantee reported in the literature. As a result, the cost-benefit analysis in this report projects the NPV for various pricing scenarios for a 25-year period.

As previously described, solar PV panels may reasonably be estimated to degrade and experience capacity losses of approximately one per cent annually (Alghamdi, Bajah & Wu, 2017, p. 17; Branker, Pathak & Pearce, 2011, p. 4476). The analysis for this report considers that annual production will decrease at a fixed rate of one per cent per year over the system's expected 25-year lifespan. The amount of surplus energy to be sold to the grid is based on that annual production total minus the onsite consumption, which is expected to stay constant for the period.

Estimated Project Costs

Material and installation costs for this project were quoted to ENMAX Solar by Opsun Systems Ltd. Based on the Opsun quote, ENMAX Solar produced budget estimates for this cost-benefit analysis. An overview of projected project costs (excluding GST) are detailed in Table 2. The cost estimate provided by ENMAX Solar is specific to the proposed solar carport system designed for this project and includes only those items that are necessary and appropriate for solar carports to be installed on this site and to cover 76 stalls.

Specifically, this project would require 576 solar PV modules (400W), seven 33.3 kW inverters, and 288 power optimizers, which are common for solar PV installations, including rooftop systems. The aluminum carport structure and foundation piles are unique additional costs for solar carport projects. Foundation piles present a variable cost as this is dependent on the type of piles required. In designing this hypothetical project, three types of foundation options were considered. Ballasted concrete blocks may be the most affordable option, however, Opsun and ENMAX Solar advised that this option would require very large concrete blocks that would result in lost parking spaces and poor aesthetics (D. Barry, personal communication, August 31, 2018). To ensure that the lot retains the current number of parking spaces (the site's primary land use and revenue source for the CPA) it is necessary to drill piles into the ground and pour a concrete and reinforced steel foundation. Since Lot 59 has utilities running underground (see the satellite image showing known utilities through the site in Appendix D) a geotechnical report is required to determine if driven or helical screw piles are required for this site. Since it is

unknown which type of foundation would be required, the estimated costs for this project anticipates the costlier option – 64 helical screw piles.

Table 2

Estimated Project Costs for a 160 KW Solar Carport Project in Lot 59 (2018\$)

| <u>Expense Item</u> | <u>Budgeted Cost</u> |
|---|----------------------|
| Solar PV modules | 196,000 |
| Inverters | 21,000 |
| Power optimizers | 26,000 |
| System materials (cables, switch gear, AC and DC disconnects, etc.) | 90,000 |
| Design and permits | 20,000 |
| Installation labour | 50,000 |
| Aluminum carports | 230,000 |
| Geotechnical report | 3,900 |
| Foundation piles (material and installation) | 9,984 |
| Total (excluding GST) | 666,884 |

Projected Operations and Maintenance Costs

As explained by ENMAX Solar (D. Barry, personal communication, September 11, 2018), solar PV systems are generally considered maintenance-free as the glazed panels of the solar modules should be self-cleaning with rain or snow run-off and there are no ongoing operating costs after installation. As detailed in the literature, inverters may be anticipated to warrant replacement every ten years. This is consistent with the standard warranty applicable to the inverters recommended for this project. Inverters typically have a design life of 20 years or more, however this has yet to be proven and the end of life failure rate is not clear (D. Barry, personal communication, September 11, 2018). Based on this, the cost-benefit analysis for this project conservatively budgets for inverters to be replaced every ten years.

Subsidies

Although transfers between entities are traditionally excluded from cost-benefit analysis, the net agency cost to the City or the CPA is an important consideration that would impact a decision to pursue a solar carport project. To address this, the cost-benefit analysis for this project considers the full project costs and adds the AMSP subsidy to show the net costs to the City or the CPA. By excluding the portion of the AMSP subsidy paid by Calgarians, the analysis further shows the net social benefits.

As detailed in the jurisdictional scan, there are few funding sources available which could reduce the cost of a solar carport project for the City and the CPA. Of those reviewed, it is most feasible that a solar carport project could receive funding from the AMSP, provided the City’s Energy Management Office supports an application.

Although loans and grant funding may also be available through the FCM Green Municipal Fund, loans will not reduce the initial cost of a solar carport project and, while some

grant funding may be possible as well, it is less clear that a solar carport project would be eligible to receive support, so this option is excluded from the analysis.

Benefits

Electricity Cost Savings and Revenues

Although Lot 59 consumes approximately 4,231 kWh of electricity each year, the proposed solar carport system would produce 193,927 kWh in the first year, producing a surplus of 189,696 kWh of electricity in the first year. On that basis, the cost-benefit analysis for this report contemplates that the CPA would utilize 4,231 kWh of energy onsite to offset commodity and delivery charges and sell the annual surplus to the grid.

Benefits of Energy Consumed On-site

In the absence of publicly available electricity rates applicable to the City, this analysis calculates the value of energy consumed on-site based on forecasted market consumer rates. If the City's electricity rates are higher than forecasted in this report's cost-benefit analysis, the financial benefit of investing in solar carports will be enhanced. If electricity rates end up being lower than forecasted in this report, investments in solar carports may be less financially beneficial.

Based on these considerations, the cost-benefit analysis undertaken for this report forecasts wholesale energy prices for electricity consumed onsite using a base case with current price-capped regulated rate option price of 6.8 cents/kWh through 2021, conservatively expecting that the cost of wholesale electricity will stay consistent in real dollars over the lifetime of the solar carport infrastructure and assuming that the regulated rates reflect the opportunity costs of production. Sensitivity analyses forecast wholesale electricity rates increasing at slightly higher than the rate of inflation, consistent with national trends where electricity has generally increased by approximately three percent. This sensitivity analysis projects that, after the regulated rate freeze ends, the real commodity price will increase by one per cent per year.

This analysis also incorporates delivery costs offset for energy consumed on-site that the CPA otherwise pays in relation to energy drawn from the grid. The forecast for this uses the CPA's 2017 transmission and delivery costs for Lot 59. In Alberta, transmission rates are regulated by the Alberta Utilities Commission whereas distribution charges, including monthly costs for billing, meter reading, equipment and maintenance, are determined by energy service providers.

Large Micro-Generation Sales to the Grid

In accordance with the Alberta Micro-Generation Regulation, solar PV systems larger than 150 kW are compensated at the pool price for the billing period. The pool price forecast used for this analysis is derived from an annual 15-year pool price forecast prepared by the Calgary-based EDC Associates Ltd. (2018). EDC Associates Ltd.'s second quarter update to its

annual forecast provides nominal values for two scenarios through 2032 based on current provincial and federal policies in partial coal-to-gas scenarios, recognizing that Alberta is currently phasing out coal production and transitioning to a capacity market to support investment in renewable energy production (pp. 22-29). EDC Associates Ltd. reiterates that it is very difficult to forecast the Alberta electricity market (p. 211) but makes its forecasts assuming energy demand in the province will continue to grow over the next 15 years (p. 16). Scenario #1 assumes that the province's transition to a capacity market is successful, expecting 400 MWh expected unserved energy (EUE) (pp. 21-22, 258). Scenario #2 provides for a lower pool price based on greater production of thermal supply, anticipating a resource adequacy target of 400 MWh EUE + 3.2 percent (pp. 22, 225-227, 265). For the purpose of this analysis, the EDC Associates Ltd. nominal pool price forecast values through 2032 are converted to 2007 dollars using a forecasted value for inflation using the Canadian consumer price index (p. 240) and then converted to 2018 real dollars using inflationary data from the Bank of Canada Inflation Calculator (2018). The forecast beyond 2032 is derived by calculating the compound annual growth rate for the EDC Associates Ltd. Forecast and applying that number through 2043.

Benefits of Offsetting Carbon Emissions

The social benefit of offsetting carbon emissions can be calculated by multiplying the solar carport system's annual electricity production by the Alberta's annual emissions intensity for the electricity system (grams of CO₂ equivalent emissions per kWh of electricity generated, as described above) to identify how much carbon the system offsets each year. If Alberta's annual emissions intensity decreased over the lifetime of the solar carport project, the social benefits of offsetting carbon emissions would decrease as well and theoretically, this should be the case as renewables offset fossil fuel production. However, the cost-benefit analysis for this report conservatively assumed that Alberta's emissions intensity will stay constant at 790g/kwh over the lifetime of the system. Although Alberta is forecasting decreased emissions in the electricity sector, plans to phase out coal production, and is projecting that 30 per cent of Alberta's electricity production will come from renewable sources by 2030 (Government of Alberta, 2018, para. 8), there is significant uncertainty around the amount and potential of future coal-to-gas conversion in the province (Alberta Electrical System Operator, 2017, p. 19) and electricity demand – including demand for natural gas – in Alberta is forecasted to increase (Alberta Energy Regulator, 2018, paras. 3-5). So, even with a decrease in coal emissions, there may be an increase in emissions from growth in natural gas production as this expands to meet demand. Additionally, the Government of Alberta's latest Climate Leadership Plan Progress Report shows that the province is not currently on track to meet its target to reduce the Alberta electricity system emissions intensity (Government of Alberta, 2017a, p. 30).

Although the City of Calgary has set emissions reductions targets and committed to actions to mitigate climate change, the City does not currently use a carbon price to evaluate the value of carbon offset associated with investments in renewable energy infrastructure. Since the City has not adopted an SCC or shadow price for cost-benefit analyses, the cost-benefit analysis in this report uses a shadow price and forecasted schedule for increases based on Jaccard, Hein and Vass' (2016) estimates, adjusted to 2018 dollars, to calculate the economic benefit

associated with offsetting carbon emissions through production of renewable energy. Although Jaccard, Hein and Vass estimate numbers much higher than the base SCC used by the Government of Canada, this is still lower than both marginal cost of abatement estimated by Sawyer and Bataille and the 95th percentile SCC estimate suggested by the federal government for sensitivity analysis. In a context where a carbon price is not generally used to quantify the externalities of capital projects, the Jaccard, Hein and Vass may be beneficial because it provides a clear schedule for increases; however, decision makers should consider that even this number may not sufficiently recognize the true cost of climate change caused by carbon emissions and the benefits of investing in solar infrastructure may be much greater.

Other Benefits Not Considered

Although there may be potential to charge a premium for covered stalls, the demand for covered parking in surface lots in Calgary is unknown and may vary from location to location. Regardless, since parking fees are transfers and will apply with or without solar panels, they are omitted from the analysis for this project.

Additionally, while solar carports may present opportunities to support the transition to EVs and further reducing emissions, this would currently be at a significant additional cost and is outside the scope of this particular study.

Social Discount Rate

Since solar PV modules have a warranty of 25 years and may be expected to last up to 40 years, a social discount rate of 3.5 per cent is likely appropriate for this type of project, which does not crowd out private investment, and will have an impact of less than 50 years. This report includes sensitivity analyses for 2.5 and 7.0 per cent in accordance with Boardman, Moore and Vining's recommendations (2010, p. 326) and 0.0 per cent to reflect that, in the context of climate change and in accordance with Gagné (2014, p. 5), future generations may not be better off than today's.

COST-BENEFIT ANALYSIS RESULTS

This section provides the results of the NPV calculations using the considerations and parameters previously described to show the net agency and net social costs (or benefits) associated with a hypothetical solar carport project in two scenarios: one where electricity prices are low, and one where electricity prices are higher. These results show the costs and benefits that the CPA and society may expect over the lifetime of a solar carport project.

Table 3

Net Present Value of Investment, Scenario 1 - Low Electricity Prices (2018\$)

| Net Agency Cost | | | | | |
|---|------------------|-------------------|----------------|----------------|-----|
| <u>Installation Costs</u> | | | | | |
| Installation costs (including GST) | 700,228 | | | | |
| Less: AMSP subsidy | (166,721) | | | | |
| Net installation costs | <u>533,507</u> | | | | |
| Net installation costs per stall | <u>7,020</u> | | | | |
| | | Discount Rate (%) | | | |
| | | 0.0 | 2.5 | 3.5 | 7.0 |
| <u>Operating and Maintenance Costs</u> | | | | | |
| Inverter replacements | 42,000 | 29,221 | 25,441 | 16,102 | |
| <u>Savings</u> | | | | | |
| Cost savings | (216,567) | (163,463) | (147,567) | (107,459) | |
| Net agency cost | <u>358,940</u> | <u>399,265</u> | <u>411,382</u> | <u>442,151</u> | |
| Net agency cost per stall | <u>4,723</u> | <u>5,253</u> | <u>5,413</u> | <u>5,818</u> | |
| <u>Net Social Cost (Benefit), Calgarian Perspective</u> | | | | | |
| Net agency cost | 358,940 | 399,265 | 411,382 | 442,151 | |
| Add: | | | | | |
| Calgarian portion of subsidy | 50,798 | 50,798 | 50,798 | 50,798 | |
| Deduct: | | | | | |
| Calgarian portion of GST | (1,175) | (1,175) | (1,175) | (1,175) | |
| Social value of avoided emissions | (739,048) | (510,571) | (444,898) | (287,164) | |
| Net social cost (benefit), Calgarian perspective | <u>(330,486)</u> | <u>(61,684)</u> | <u>16,106</u> | <u>204,609</u> | |
| Net social cost per stall | <u>(4,348)</u> | <u>(812)</u> | <u>212</u> | <u>2,692</u> | |

The parameters used for these calculations are provided in Appendix E and the full calculations are provided in Appendix E. Summaries of these results are provided in Tables 3

and 4 below and the spreadsheets containing the full calculations for this analysis are available from the author or the CPA upon request.

Table 4

Net Present Value of Investment, Scenario 2 - High Electricity Prices (2018\$)

| Net Agency Cost | | | | | |
|--|------------------|-------------------|------------------|------------------|-----|
| <u>Installation Costs</u> | | | | | |
| Installation costs (including GST) | 700,228 | | | | |
| Less: AMSP subsidy | <u>(166,721)</u> | | | | |
| Net installation costs | <u>533,507</u> | | | | |
| Net installation costs per stall | <u>7,020</u> | | | | |
| | | Discount Rate (%) | | | |
| | | 0.0 | 2.5 | 3.5 | 7.0 |
| <u>Operating and Maintenance Costs</u> | | | | | |
| Inverter replacements | 42,000 | 29,221 | 25,441 | 16,102 | |
| <u>Savings</u> | | | | | |
| Cost savings | <u>(230,622)</u> | <u>(173,355)</u> | <u>(156,247)</u> | <u>(113,179)</u> | |
| Net agency costs | <u>344,886</u> | <u>389,373</u> | <u>402,701</u> | <u>436,430</u> | |
| Net agency cost per stall | <u>4,538</u> | <u>5,123</u> | <u>5,299</u> | <u>5,743</u> | |
| <u>Net Social Cost (Benefit), Calgarian Perspective</u> | | | | | |
| Net agency cost | 344,886 | 389,373 | 402,701 | 436,430 | |
| Add: | | | | | |
| Calgarian portion of subsidy | 50,798 | 50,798 | 50,798 | 50,798 | |
| Deduct: | | | | | |
| Calgarian portion of GST | (1,175) | (1,175) | (1,175) | (1,175) | |
| Social value of avoided emissions | <u>(739,048)</u> | <u>(510,571)</u> | <u>(444,898)</u> | <u>(287,164)</u> | |
| Net social cost (benefit), Calgarian perspective | <u>(344,540)</u> | <u>(71,576)</u> | <u>7,426</u> | <u>198,889</u> | |
| Net social cost (benefit) per stall, Calgarian perspective | <u>(4,533)</u> | <u>(942)</u> | <u>98</u> | <u>2,617</u> | |

As shown in Tables 3 and 4 and further detailed in Appendix F, a solar carport investment is more beneficial in scenarios where electricity prices are higher, however at the forecasted prices, there would be a net cost to the CPA or the City even if it receives the maximum subsidy that may be available through the AMSP program, regardless of the social discount rate applied.

In the base case analysis (3.5 per cent social discount rate), considering the social value of avoided emissions, a solar carport project would have a net cost to society of \$212 per stall over the 25-year lifespan of a solar carport installation. In sensitivity analyses using lower social discount rates (2.5 and zero per cent), the results show positive net benefits to society in both electricity price scenarios.

DISCUSSION

The research conducted for this project considered the costs and benefits of investing in solar carports in surface parking lots, including benefits to society associated with offsetting carbon emissions through the production of renewable energy, on a cost-per-stall basis. It also looked at considerations affecting the feasibility and viability of installing solar carports in surface parking lots and circumstances and conditions where it would be optimally beneficial for the City and the CPA to invest in solar carport infrastructure. This discussion draws on findings from the literature review, administrative review, and cost-benefit analyses conducted to comprehensively address these research questions.

Various factors, including the regulatory framework to compensate micro-generators, electricity prices, the location and characteristics of a surface parking lot site, and the cost of materials impact the feasibility of solar carport projects. Previous research indicates that solar carports may pay for themselves in seven to 16 years (Alghamdi, Bajah & Wu, 2017, pp. 16-17; Figueiredo, Nunes & Brito, 2017, pp. 1193-1195). Based on the results of this research, considering only costs and benefits such as electricity cost savings and revenues from surplus energy sales to the grid, this is not the case in the Calgary context as all scenarios considered resulted in a negative NPV. However, this research also shows that when the social value of avoided carbon emissions is considered, there are social benefits that may make solar carport projects beneficial over the lifetime of the project. Additionally, if available, subsidy programs from other levels of government could be used to reduce the cost of a solar carport to the City or the CPA so that it may more feasibly take advantage of opportunities to add a beneficial use to otherwise underutilized spaces.

The benefits of environmental investments like solar carports become stronger in analyses that use a lower social discount rate, recognizing that, under the threat of climate change, future generations may not be better off than current generations. Further, public parking providers seeking to achieve public policy objectives to reduce carbon emissions can be less concerned about financial rates of return than private providers. In the context of these considerations, it is reasonable to give the social benefits of solar PV investments more weight.

Surface Parking Lot Location and Land Use Considerations

This research demonstrates the potential social benefits that can arise from solar carport investments, however, solar carports are not possible or feasible for all surface parking lots. There are several key factors that impact the feasibility of a solar carport project. First, because it may take 25 or more years to experience financial or social benefits from a solar carport investment, it is important to choose a surface parking lot that will exist for at least that period of time. Given city policies that may limit or reduce the amount of surface parking in Calgary, few current parking lots may endure to meet these criteria as it may be reasonably expected that many will be redeveloped for other uses in the future. Parking lots that exist to provide vehicle access to sites for other land use purposes (e.g. parks, recreation facilities, malls, schools, etc.) may be the best candidates for solar carport investments on this basis, as those land uses may be more likely to endure than sites that exist for surface parking only. Additionally, it is important

that a site have good sun exposure that is unlikely to be shaded by neighboring developments now or in the future and it is important that the land use zoning includes the ability to generate power onsite. For sites where this is not currently permitted, this may be achieved through applications for land use re-designations.

Further, it is not currently possible to implement solar carport projects that export to the grid within ENMAX's secondary network boundaries, regardless of a site's zoning. Most of the City-owned parking lots managed by the CPA are located within a secondary network, limiting the present possibilities for solar carport projects. Micro-generation projects in these areas may be possible in the near future, however it is not known if there will be additional costs to connect to the grid within existing secondary networks.

Project Benefits

Electricity Cost Savings and Revenues

The regulatory environment provides the basis for incentives and benefits associated with investments in renewable energy infrastructure. Under the current Alberta Micro-generation Regulation, smaller micro-generation projects can be compensated the wholesale rate of electricity for both energy consumed onsite and energy sold to the grid, while larger projects, like the one contemplated for this research, are compensated at the pool price for energy sold to the grid. Based on this framework, it is better value to consume electricity produced onsite, and it may be beneficial to have slightly smaller projects as forecasts for the wholesale price of electricity are slightly higher than pool price forecasts.

Solar carport investments are more favourable when electricity rates are higher, however, even the high electricity price scenario contemplated for this analysis based on current energy cost forecasts produced negative NPV values. In the absence of more accurate electricity pricing data, this research used market forecasts for pool prices and wholesale prices of electricity. If the electricity rates paid to ENMAX by the City end up being higher than projected in this analysis, then investments in solar infrastructure, including solar carports, will generate more financial savings and returns to the CPA and the City.

Benefits of Offsetting Carbon Emissions

Further to cost savings and revenues that may be incurred through renewable micro-generation, it is essential to consider the social value of carbon to appropriately understand how solar carport projects may be beneficial to society. Without applying a value for the marginal cost of abatement to achieve carbon emissions reductions, a solar carport project may never be viewed as a cost-effective or sound investment, especially since political will is necessary to support investments that may not be financially profitable but will provide broader benefits to the community and achieve the City's goals.

When the value of offsetting carbon emissions is considered in the cost-benefit analysis, solar carports become a better investment, because the benefits come closer to (or exceed) the costs. However, as renewables replace fossil fuel energy production, Alberta's emissions

intensity may be expected decrease and this will affect the value that may be attributed to offset emissions in cost-benefit analyses.

While the GHG offset associated with individual carport projects may be relatively small in the larger context of emissions (approximately 120 to 150 tonnes offset annually over 25 years), a solar carport project of the size considered for this research would produce a social value of avoided emissions of \$10,000 in year one that would continue to increase over the lifetime of the project if Alberta maintains its existing emissions intensity. In the context of surface parking lots, which typically have only one use – to store vehicles that produce GHG emissions – this benefit is noteworthy as it adds a benefit that would not otherwise exist.

Notably, the cost of abatement estimates used for this analysis may still underestimate the real costs to society associated with greenhouse gas emissions. Use of a higher value, like those posited by Sawyer and Bataille, or the 95th percentile estimate suggested by the federal government for sensitivity analysis could produce NPV results that are even more favourable to solar carport investments and better reflective of the significant costs that society could incur due to the negative effects of climate change.

Solar Carport Project Costs

Solar Carport Infrastructure

The features that make solar carports unique are also the reasons that they may be more expensive and cost-prohibitive than other solar PV applications. While the cost of solar modules, inverters, and optimizers is generally common across types of solar installations, cost of the carport structure and necessary foundation piles, which are applicable only in this context, comprise approximately 40 per cent of project costs. Although this makes it apparent that other types of PV installations may be more cost-effective means of renewable micro-generation, it is worth noting that rooftop PV applications may also have additional costs not considered here. For example, older buildings may not have been built to withstand the added weight of solar modules on the roof. This research also projects costs conservatively. The costs for a real solar carport project may be lower if the cost of aluminum decreases or depending on site characteristics. For example, the underground infrastructure causes cost increases if helical screw piles are required.

Due to economies of scale, larger projects would also likely be more cost-effective, but Lot 59 is the largest surface parking lot outside of the secondary network that is managed by the CPA and is the only lot that might experience cost-efficiencies on this basis. Other parking providers, including other City business units, that operate larger lots outside of the secondary network might benefit more from cost-efficiencies.

Subsidies to Reduce Agency Costs

As demonstrated in the cost-benefit analysis for this research, subsidies like the AMSP can reduce the upfront cost to the agency, making potential capital investments in solar carports more feasible for the City and the CPA. Given that solar carport investments in the Calgary

context may have a net cost on purely financial basis over the lifetime of a project but have the potential to create social benefits where none would otherwise exist, it makes sense that transfers from other levels of governments should support municipalities to contribute to federal and provincial policy objectives to reduce carbon emissions and incent investments that create these positive externalities. In the current context, larger subsidies are available for smaller solar projects, so in combination with the greater compensation available to small microgenerators, it may be more beneficial for an agency to invest in a slightly smaller system (i.e. less than 150 kW nameplate capacity). Changes to the AMSP or the introduction of similar programs that increased the percentage of project costs that could rebated with government transfers (e.g. 40 per cent instead of 25 per cent) would likely make solar PV investments even more feasible and attractive to local entities.

RECOMMENDATIONS (OR OPTIONS FOR CONSIDERATION)

Based on the findings detailed above, there are six key recommendations for the CPA to consider as it works to identify opportunities for investments that will enhance environmental sustainability and generate benefits for Calgarians.

Recommendation 1: Work with the City’s Energy Management Office to Identify and Pursue Solar PV Projects in Parking Contexts

As demonstrated by this analysis of a hypothetical solar carport project on Lot 59 in Sunnyside, solar carports provide an opportunity to make better use of land used for parking, create social benefits on a per stall basis, and contribute to City sustainability objectives.

Additional resources and access to subsidy programs to reduce the cost to the CPA may be available through the Energy Management Office

By developing relationships with the Energy Management Office, the City may also become more aware of opportunities for other City business units that provide parking to become more sustainable through solar PV applications.

Recommendation 2: Exhaust Opportunities for Rooftop Solar

Although this research shows that a solar carport project at Lot 59 would result in social benefits, the quote provided for this project shows that material and installation costs for carport infrastructure make solar carports much more expensive than other types of solar PV applications. For example, rooftop solar applications do not require the expensive aluminum structure or foundation pilings that solar carports require. As a result, the CPA should look first to environmental investments, like rooftop solar, that have lower costs and equivalent benefits and will provide a better return on investment. While City solar carport projects may be eligible for subsidies like the AMSP which could reduce the cost to the agency, the City’s Energy Management Office is most likely to prioritize projects that are more cost-effective and will provide a better return on investment for the City, so it is reasonable to expect that the CPA is more likely to gain support and resources from the City to pursue rooftop PV projects.

Additionally, solar PV applications including solar carports will be most beneficial on sites where most or all of the energy produced can be consumed onsite. The Impound Lot could be a feasible location for solar infrastructure due to its location outside of the secondary network and ability to consume most energy it would produce onsite. Although most CPA buildings (e.g. parkades and office buildings) are located within an ENMAX secondary network, and the CPA should be cautioned that not all buildings are well suited to rooftop solar, the CPA may also explore opportunities for rooftop solar on enclosed standalone structures within ENMAX secondary network. Parkades, which consume more electricity than surface parking lots may be more likely to consume all of the energy produced by a solar system onsite. In the event that this is not the case, rooftop solar may become more beneficial when it becomes possible for microgenerators to export surplus renewable energy to the grid, likely sometime after 2022.

Recommendation 3: Take Advantage of Opportunities to Reduce the Cost or Enhance the Benefits of Solar Carports

Although the CPA should first look to rooftop solar applications as a more cost-effective investment, this research has demonstrated that a solar carport project has the potential to produce net social benefits. Solar carports would further become a more cost-effective investment for the City or the CPA if the cost decreased or the benefits increased. Specifically:

- Decreases in the cost of carport infrastructure would make a project more feasible (e.g. if the cost of aluminum decreased, or if a less expensive foundation pile option was possible);
- The cost to the CPA would be decreased if more subsidies became available (e.g. if the province increases the percentage of eligible expenses provided for the AMSP rebate, or if other transfers become available);
- The benefits of solar PV applications would increase if electricity prices increase beyond the rates forecasted for this analysis (this will be important to monitor when the City renegotiates its electricity agreement with ENMAX); and
- The benefits of solar PV applications would increase if the regulatory environment changes to enhance the incentives for microgenerators (i.e. if the province changed the rate of compensation).

Recommendation 4: Identify Suitable Surface Parking Sites

In the event that the CPA chose to pursue investments in solar carports, solar carports are likely best suited for surface parking, as existing open air parkades likely are not suited to the requisite drilled foundation piles and may not be able to withstand the added weight of concrete ballast block foundation that would be needed to support the carport structure. Even if a parkade can withstand the added weight of concrete ballast blocks, these would reduce the floor space available for parking spaces.

As demonstrated by this research, a limited number of existing surface parking lots managed by the CPA are suitable for solar carports based on location and zoning. Additional site characteristics may further limit the feasibility of solar carport installations. For those lots that meeting zoning requirements and exist outside of the secondary network, the CPA should identify the long-term plans for these sites, what known utilities exist below those sites, and the solar potential for those sites.

Recommendation 5: Consider Conducting Additional Cost-Benefit Analyses

If the CPA decides to undertake further analysis on the economic viability of solar modules, cost-benefit analyses should consider additional scenarios and sensitivity analyses that will examine how the net costs and benefits would change as parametric assumptions change to help the agency to make more informed decisions about potential investments. Additional analysis should consider alternative and additional carbon pricing (e.g. including government SCC values) and emissions intensity assumptions (e.g. anticipating that Alberta's emissions intensity may decrease over the lifetime of a project). Additional electricity prices that the CPA

may be paid for surplus energy production should also be used; it would be useful to consider updated market forecasts, forecasts based on the actual City of Calgary energy rates, and rates that would create break-even or positive NPV scenarios.

Additional sensitivity analysis should also consider a range of additional social discount rates. For example, it may be beneficial to consider the four per cent rate used by Alberta Transportation, the CPA's borrowing rate, or other rates that are considered best practice and would support comparability with other studies. These findings should be presented using graphical methods depicting the NPV values on the y-axis and changing parameter values on the x-axis.

Recommendation 6: Consider Solar Infrastructure Investments as Part of Future Planning

Although in the current context, the CPA should likely look first to opportunities for rooftop solar as a more cost-effective investment and the financial benefits of solar carports may be limited, this research has shown that there are clear social benefits to solar carports and has identified factors that may make solar carports more feasible or beneficial in the future. The fact that solar carports are an expensive investment does not negate their benefits or opportunities to make surface parking lots a more sustainable use of land.

Given that solar PV applications are most beneficial when all or most of the energy produced can be consumed onsite, solar carports may become more feasible and beneficial in the event that the City or the CPA begins providing EV charging in surface lots.

Opportunities for the CPA to invest in rooftop solar or solar carports will also dramatically increase in the event that ENMAX Power Corporation develops a mechanism for microgenerators to export power to the grid within the downtown secondary network, as most of the CPA's off-street facilities are located inner-city.

CONCLUSION

This research investigated factors impacting the feasibility of municipal investment in solar carport infrastructure and calculated the costs and benefits of a hypothetical solar carport project at surface parking lot owned by the City of Calgary and managed by the CPA. Solar carports present a unique opportunity to transform surface parking lots, which have negative effects on the environment, into multi-use spaces that offset harmful carbon emissions and generate benefits for society. In the right circumstances, where investment costs are low and electricity prices are high, solar carports may also produce financial benefits for parking providers by providing a mechanism to offset energy costs and generate revenues by selling renewable energy to the power grid; however, due to the cost of materials and low electricity prices, this was not the case for the hypothetical project considered for this research,

This analysis for this project showed that while solar carport investments are expensive, in the context of climate change, where increasing temperatures will create immense costs to society, solar carport projects can produce a net benefit to society by offsetting carbon emissions. A solar PV project will be more beneficial for an agency if the costs of materials decrease, site features warrant lower costs, the cost of electricity is higher than forecasted, or the regulatory context changes to provide better incentives for cost savings or revenue generation. Increases to government subsidies could also reduce the initial cost of the investment for the local agency.

Given the potential benefits to Calgarians and the opportunity to contribute to important public policy objectives shared by all levels of government, the CPA should work to identify opportunities to pursue solar PV projects in parking contexts, first exhausting opportunities for rooftop solar, which may be less expensive than solar carport projects. The Impound Lot may be ideal for this as it exists outside of the ENMAX secondary network and consumes a greater amount of energy onsite than any surface lot operated by the CPA.

Additionally, the CPA should continue to monitor and explore the possibility for solar carport projects, actively evaluating potential sites (see Appendix C), determining the potential cost of carport infrastructure at various locations (e.g. what kind of foundation piles would be required), taking advantage of potential subsidies to reduce agency costs, and considering how to take advantage of potential changes in the local administrative context that may arise (e.g. changes to the Micro-generation Regulation, the City's electricity price agreement with ENMAX, and the rules governing ENMAX's secondary network downtown).

REFERENCES

- Alberta Energy Regulator. (2018). *Natural gas demand*. Retrieved from <https://www.aer.ca/providing-information/data-and-reports/statistical-reports/natural-gas-demand>
- Alberta Electric System Operator. (2016). *Alberta's wholesale electricity market transition recommendation*. Retrieved from <https://www.alberta.ca/documents/Electricity-market-transition-report.PDF>
- Alberta Electric System Operator. (2017). AESO 2017 long-term outlook. Retrieved from <https://www.aeso.ca/download/listedfiles/AESO-2017-Long-term-Outlook.pdf>
- Alberta Electric System Operator. (2018). *Capacity market questions and answers*. Retrieved from <https://www.aeso.ca/assets/Uploads/CapacityMarket-QA-WEB.pdf>
- Alberta Transportation. (2017). *Benefit cost model user guide*. Retrieved from <http://www.transportation.alberta.ca/Content/docType233/Production/ATBCMUserGuideV2.pdf>
- Alberta Utilities Act: Micro-generation regulation. (2017). *Alberta Regulation 27/2008, with amendments up to and including Alberta Regulation 140/2017*. Retrieved from the Alberta Queen's Printer http://www.qp.alberta.ca/documents/Regs/2008_027.pdf
- Alghamdi, A., Bahaj, A. & Wu, Y. (2017). Assessment of large scale photovoltaic power generation from carport canopies. *Energies*, 10(686), 1-22.
- Arrow, K., Cropper, M., Gollier, C., Groom, B., Heal, G., Newell, R., ... Weitzman, M. (2012). How should benefits and costs be discounted in an intergenerational context? The views of an expert panel. *Resources for the Future*. Retrieved from <http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-12-53.pdf>
- Bank of Canada. (2018). *Inflation calculator*. Retrieved from <https://www.bankofcanada.ca/rates/related/inflation-calculator/>
- Bazilian, M., Onyeji, I., Liebreich, M., MacGill, I., Chase, J., Shah, J., Gielen, D., Arent, D., Landfear, D. & Zhengrong, S. (2013). Re-considering the economics of photovoltaic power. *Renewable Energy*, 53, 329-338.
- Boardman, A., Moore, A. & Vining, R. (2010). The social discount rate for Canada based on future growth in consumption. *Canadian Public Policy*, 36(3), 325-343.
- Boychuk, J. & Oelke, L. (2017, September 15). Solar PV covered parking benefits. *Canadian Parking Association*. Retrieved from <http://canadianparking.com/solar-pv-covered-parking-benefits/>
- Branker, K., Pathak, M. & Pearce, J. (2011). A review of solar photovoltaic levelized cost of electricity. *Renewable and Sustainable Energy Reviews*, 15, 4470-4482.

- Brown, D. (2018). Capacity market design: Motivation and challenges in Alberta's electricity market. *The School of Public Policy Publications*. Retrieved from <https://www.policyschool.ca/wp-content/uploads/2018/03/Electricity-Market-Brown.pdf>
- Calgary Land Use Bylaw. (2018). *City of Calgary Bylaw 1P2007*. Retrieved from <http://lub.calgary.ca/>
- Calgary Parking Authority Bylaw. (2017). *City of Calgary Bylaw 28M2002*. Retrieved from <http://www.calgary.ca/CA/city-clerks/Documents/BCC-Docs/Calgary%20Parking%20Authority%20-%20Bylaw.pdf>
- Calgary Parking Authority. (2017). *Upgraded ParkPlus machines are coming to Calgary streets*. Retrieved from <https://www.calgaryparking.com/documents/10184/1384421/Upgraded+ParkPlus+Pay+Machines+Coming+to+Calgary+Streets+-+Media+Release+-+February+22%2C+2017.pdf/2196372b-d4c9-4392-9fe5-65012db35da2>
- Calgary Parking Authority. (2018). *Land use summary report*. Calgary, AB.
- Calgary Parking Policies. (2017). *Council Policy TP017*. Retrieved from <http://www.calgary.ca/CA/city-clerks/Documents/Council-policy-library/TP017-CalgaryParkingPolicies.pdf>
- CBC. (2017, February 14). How chinook winds bring warmth to southern Alberta. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/calgary/calgary-chinook-valentines-day-record-high-torneby-environment-canada-1.3982463>
- Christian, C. (2014, October 23). Wood Buffalo goes green with new operations centre. *Journal of Commerce*. Retrieved from <https://canada.constructconnect.com/joc/news/technology/2014/10/wood-buffalo-goes-green-with-new-operations-centre-1002892w>
- City of Calgary. (2012). *Calgary transportation plan*. Retrieved from http://www.calgary.ca/Transportation/TP/Documents/CTP2009/calgary_transportation_plan.pdf
- City of Calgary. (2013). *imagineCALGARY: Calgary's plan for long range sustainability*. Retrieved from <http://www.calgary.ca/PDA/pd/Documents/Resource-library/2013-imagine-calgary-plan.pdf>
- City of Calgary. (2017a). *Municipal development plan [office consolidation]*. Retrieved from <http://www.calgary.ca/PDA/pd/Pages/Municipal-Development-Plan/Municipal-Development-Plan-MDP.aspx>
- City of Calgary. (2017b). *Solar energy*. Retrieved from <http://www.calgary.ca/CS/IIS/Pages/Solar-Energy-Projects.aspx>

- City of Calgary. (2018). *Climate resilience strategy*. Retrieved from http://www.calgary.ca/UEP/ESM/Documents/ESM-Documents/Climate_Resilience_Plan.PDF
- Creedy, J. & Passi, H. (2018). Public sector discount rates: A comparison of alternative approaches. *The Australian Economic Review*, 51(1), 139-157.
- Dodge, D. (2017). New Simons has largest solar system in Edmonton. *Green Energy Futures*. Retrieved from <http://www.greenenergyfutures.ca/episode/176-simons-solar-largest-edmonton>
- Economic Development and Trade. (2016). *Greenhouse gas emissions by municipality* [Data file]. Retrieved from <https://regionaldashboard.alberta.ca/region/calgary/greenhouse-gas-emissions/#/?from=2006&to=2016>
- EDC Associates Ltd. (2018). *Quarterly forecast update: Second quarter 2018*. Retrieved from <http://edc-associates-ltd.myshopify.com/products/2018-quarterly-forecast-q2-update> [City of Calgary annual subscription]
- ENMAX Power Corporation. (2017). *Network boundary downtown*. Retrieved from https://www.enmax.com/GenerationAndWiresSite/Documents/GI_Network_Boundary_Downtown.pdf
- ENMAX Power Corporation. (2018). *Distribution tariff rate schedule*. Retrieved from <http://www.auc.ab.ca/Shared%20Documents/ENMAXPower-RateSchedule.pdf>
- ENMAX Power Corporation. (n.d.). *Secondary network systems*. Retrieved from <https://www.enmax.com/generation-wires/transmission-and-distribution/our-system/distributed-generation/secondary-network-systems>
- Environment and Climate Change Canada. (2016). Technical update to Environment and Climate Change Canada's social cost of greenhouse gas estimates. *Government of Canada*. Retrieved from http://publications.gc.ca/collections/collection_2016/eccc/En14-202-2016-eng.pdf
- Erickson, L. & Jennings, M. (2017). Energy, transportation, air quality, climate change, health nexus: Sustainable energy is good for our health. *AIMS Public Health*, 4(1), 47-61.
- Federation of Canadian Municipalities. (2018a). *Capital projects funding: Green municipal fund*. Retrieved from <https://fcm.ca/home/programs/green-municipal-fund/what-we-fund/capital-projects.htm>
- Federation of Canadian Municipalities. (2018b). *Energy efficiency and recovery funding*. Retrieved from <https://fcm.ca/home/programs/green-municipal-fund/what-we-fund/eligibility/energy-funding.htm>
- Figueiredo, R., Nunes, P. & Brito, M. (2017). The feasibility of solar parking lots for electric vehicles. *Energy*, 140, 1182-1197.

- Gagné, L. (2014). *The social discount rate: A global policy error* (Unpublished work). University of Victoria, Victoria, BC.
- Glemarec, Y. & Puppim de Oliveira, J. (2012). The role of the visible hand of public institutions in creating a sustainable future. *Public Administration and Development*, 32, 200-214.
- Golden, J. (2006). Photovoltaic canopies: Thermodynamics to achieve a sustainable systems approach to mitigate the urban heat island hysteresis lag effect. *International Journal of Sustainable Energy*, 25(1), 1-21.
- Golden, J., Carlson, J., Kaloush, K. & Phelan, P. (2007). A comparative study of the thermal and radiative impacts on photovoltaic canopies on pavement surface temperatures. *Solar Energy*, 81, 872-883.
- Government of Alberta. (2017a). *Climate leadership plan progress report 2016-17*. Retrieved from <https://open.alberta.ca/publications/climate-leadership-plan-progress-report-2016-17>
- Government of Alberta. (2017b). *Electricity price protection*. Retrieved from <https://www.alberta.ca/electricity-price-protection.aspx>
- Government of Alberta. (2018). *Phasing out coal pollution*. Retrieved from <https://www.alberta.ca/climate-coal-electricity.aspx>
- Government of Canada. (2017). *Canada's 2017 nationally determined contribution submission to the United Nations framework convention on climate change*. Retrieved from <http://www4.unfccc.int/ndcregistry/PublishedDocuments/Canada%20First/Canada%20First%20NDC-Revised%20submission%202017-05-11.pdf>
- Group Renault. (2011). *Renault launches the world's largest automotive industry solar roof project*. Retrieved from <https://media.group.renault.com/global/en-gb/groupe-renault/media/pressreleases/28666/renault-lance-le-plus-grand-projet-photovoltaique-automobile-mondial1>
- Hassan, Q., Rahman, K., Haque, A. & Ali, A. (2011). Solar energy modelling over a residential community in the City of Calgary, Alberta, Canada. *International Journal of Photoenergy*, 2011(1), 1-8.
- Heyes, A., Morgan, D. & Rivers, N. (2013). The use of a social cost of carbon in Canadian cost-benefit analysis. *Canadian Public Policy*, 39, S67-S79.
- Intergovernmental Panel on Climate Change. (2018). *Global warming of 1.5 °C, an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty: Summary for policy makers*. Retrieved from http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

- Jaccard, M., Hein, M. & Vass, T. (2016). *Is win-win possible? Can Canada's government achieve its Paris commitment... and get re-elected?* Energy and Materials Research Group, Simon Fraser University, Vancouver, BC.
- Livingston, B. (2018). The Alberta electrical grid: What to expect in the next few years. *The School of Public Policy Publications*. Retrieved from <https://www.policyschool.ca/wp-content/uploads/2018/04/AB-Electrical-Grid-Livingston.pdf>
- Ma, K. (2017 August 26). Edmonton region gets first sun-powered parking lot. *St. Alberta Gazette*. Retrieved from <https://www.stalbertgazette.com/article/edmonton-region-gets-first-sun-powered-parking-lot-20170826>
- Matthews, T. (2016). Solar photovoltaic reference array report. *Northern Alberta Institute of Technology*. Retrieved from <https://solaralberta.ca/sites/default/files/NAIT%20Reference%20Array%20Report.pdf>
- Micro-Generation Regulation, Alberta Regulation 27/2008. Retrieved from the Alberta Queen's Printer website: http://www.qp.alberta.ca/documents/Regs/2008_027.pdf
- Mooney, C. (2015 January 28). The best idea in a long time: Covering parking lots with solar panels. *The Washington Post*. Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2015/01/28/the-best-idea-in-a-long-time-covering-parking-lots-with-solar-panels/?noredirect=on&utm_term=.90f34d4942a6
- Mukhija, V. & Shoup, D. (2006). Quantity versus quality in off-street parking requirements. *Journal of the American Planning Association*, 72(3), 296-308.
- Municipal Climate Action Centre. (2018). *AMSP guidebook*. Retrieved from http://www.mccac.ca/sites/default/files/amsp_guidebook_november_2018_2.pdf
- National Energy Board. (2017a). Market snapshot: Canadian electricity prices generally increasing faster than inflation, but trends vary among provinces. *Government of Canada*. Retrieved from <https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2017/05-03cndnlctrcprcs-eng.html>
- National Energy Board. (2017b). *Canada's renewable power landscape 2017 – Energy market analysis*. Retrieved from <https://www.neb-one.gc.ca/nrg/sttstc/lctrc/rprt/2017cndrnwblpwr/ghgmssn-eng.html?=&wbdisable=true>
- Neumann, H., Schar, D. & Baumgartner, F. (2012). The potential of photovoltaic carports to cover the energy demand of road passenger transport. *Progress in Photovoltaics: Research and Applications*, 20, 639-649.
- Nordhaus, W. (2017). Revisiting the social cost of carbon. *Proceedings of the National Academy of Sciences of the United States of America*, 114(7), 1518-1528.

- Nunes, P., Figueiredo, R. & Brito, M. (2016). The use of parking lots to solar-charge electric vehicles. *Renewable and Sustainable Energy Reviews*, 66, 679-693.
- Ola, D. (2016, October 21). Round up: BrightSpot installs first LoadSpot system, Trina Solar carport, Dominion acquisition. *PV Tech*. Retrieved from <https://www.pv-tech.org/news/round-up-brightspot-installs-first-loadspot-system>
- Public Sector Accounting Board. (2018). Public sector accounting standards: PS1100 financial statement objectives . In *CPA Canada standards and guidance collection*. Retrieved from <http://voyager.library.uvic.ca/vwebv/holdingsInfo?bibId=1369762>.
- Rissman, J., Orvis, R., Riehl, B., Israel, B. & Plumptre, B. (2018). Enhancing Canada’s climate commitments: Building on the Pan-Canadian Framework. *Energy Innovation*. Retrieved from <http://energyinnovation.org/wp-content/uploads/2018/03/Canada-Energy-Policy-Simulator-Research-Note-FINAL.pdf>
- Robinson, J., Brase, G., Griswold, W., Jackson, C. & Erickson, L. (2014). Business models for solar powered charging stations to develop infrastructure for electric vehicles. *Sustainability*, 6, 7358-7387.
- Row, J., Welk, E., Lemphers, N. & Cobb, P. (2011). *Options for reducing GHG emissions in Calgary – research report*. Calgary, AB: The Pembina Institute.
- Rowlands, I. (2005). Solar PV electricity and market characteristics: Two Canadian case-studies. *Renewable Energy*, 30, 815-834.
- Sawyer, D. & Bataille, C. (2017). Taking stock: Opportunities for collaborative climate action to 2030. *Decarbonization Pathways Canada*. Retrieved from <https://www.enviroeconomics.org/single-post/2017/03/31/Taking-Stock-Opportunities-for-Collaborative-Climate-Action-to-2030>
- Smil, V. (2012). Solar energy. In D. Vasey, S. Fredericks, S. Lei & S. Thompson (Eds.), *The Berkshire encyclopedia of sustainability volume 4: Natural resources and sustainability* (440-441). Great Barrington, MA: Berkshire.
- Solar Energy Society of Alberta. (2015). *Alberta solar performance data*. Retrieved from <https://solaralberta.ca/content/alberta-solar-performance-data>
- Solar Energy Society of Alberta. (2018). *FAQs*. Retrieved from <https://www.solaralberta.ca/faqs>
- Statistics Canada. (2017). *Population and dwelling count highlight tables, 2016 census*. Retrieved from <https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/hlt-fst/pd-pl/index-eng.cfm>
- Swift, K. (2013). A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations across the United States. *Renewable Energy*, 57, 137-143.

- Thibault, B. (2016). The impact of Alberta's Climate Leadership Plan on electricity costs. *Pembina Institute*. Retrieved from <https://www.pembina.org/reports/faq1-clp-effect-on-electricity-costs.pdf>
- Timilsina, G., Kurdgelashvili, L. & Narbel, P. (2012). Solar energy: Markets, economics and policies. *Renewable and Sustainable Energy Reviews*, 16, 449-465.
- Tol, R. (2011). The social cost of carbon. *Annual Review of Research Economics*, 3, 419-443.
- Ward, R. (2018, August 28). Enmax envisions solar-powered skyscrapers that feed the grid. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/calgary/green-energy-project-calgary-alberta-1.4801936>
- Warren, F. & Lemmen, D. (2014). Synthesis. In F. Warren & D. Lemmen (Eds.), *Canada in a changing climate: Sector perspectives on impacts and adaptation* (1-18). Ottawa, ON: Government of Canada. Retrieved from https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Synthesis_Eng.pdf
- Weitzman, M. (1998). Why the far-distant future should be discounted at its lowest possible rate. *Journal of Environmental Economics and Management*, 36, 201-208.
- Zaidi K. (2009). Solar energy policy in Canada: An overview of recent legislative and community-based trends toward a coherent renewable energy sustainability framework. *Environmental Law and Policy Review*, 17(1), 108-154.

APPENDIX A – CPA SURFACE PARKING LOT ASSET SUMMARY

Table A1

Surface Parking Lots Managed and Operated by the CPA

| <u>Lot</u> | <u>Location</u> | <u>Stewardship</u> |
|----------------|---------------------------------------|-----------------------------------|
| Lot 2 | 112-4 Ave. NW, 1120-15 Ave. NW | CPA/RE&DS |
| Lot 888 | 109 Riverfront Ave. SE | RE&DS |
| Lot 6 | 311-8 St. SW, 903-8 St. SW | CPA/RE&DS/Roads |
| Lot 7 | 208, 210, 212, 222-9 Ave. SW | CPA |
| Lot 10 | 816, 820 Edmonton Tr. NE | CPA/Transportation Infrastructure |
| Lot 20 | 125, 203-14 St. NW | CPA |
| Lot 21 | 344-14 St. NW | RE&DS |
| Lot 23 | 1101 Memorial Dr. NW | Parks |
| Lot 37 | 1056 Memorial Dr. NW | Roads |
| Lot 43 | 880-11 St. SE, 1206-9 Ave. SE | CPA |
| Lot 44 | 1301-9 Ave. SE | CPA |
| Lot 45 | 1716-5A St. SW | Calgary Board of Education |
| Lot 46 | 9046 College Lane SW | Calgary Board of Education |
| Lot 55 | 539-7 Ave. SE | CMLC |
| Lot 57 | 1210 Kensington Rd. NW | CPA |
| Lot 58 | 925, 935-4 Ave. SE | CMLC |
| Lot 59 | 200 Memorial Dr. NW | Parks |
| Lot 61 | 701-11 St. SW | Parks |
| Lot 62 & 62B | 363, 407-9 Ave. SE | CMLC |
| Lot 63B & 63C | 313-10 Ave. SE | Facilities Management |
| Lot 64 | 801, 825-11 St. SW | Parks |
| Lot 66 | 808, 830-9 Ave. SW | CPA |
| Lot 71 | 603, 605, 609-3 Ave. SW, 311-5 St. SW | CPA |
| Lot 73 | 606 Confluence Way SE | CMLC |
| Lot 74 | 656 Confluence Way SE | CMLC |
| Lot 75 | 401-4 Ave. SE | CMLC |
| Lot 76 | 1735 College Lane SW | Calgary Board of Education |
| Calgary Zoo | 1320 Zoo Rd. NE | Calgary Zoo |
| Telus Spark | 220 St. George Dr. NE | Telus Spark |
| Heritage Park | 1900 Heritage Dr. SW | Heritage Park |
| Lot 67 | 409-10 St. SW | Store Front Properties |
| Trolley Square | 508-24 Ave. SW | Opus Corporation |
| MEC | 830-10 Ave. SW | Mountain Equipment Co-op |

Notes. This asset summary is derived from the CPA's 2018 Land Summary Report and is current as of September 18, 2018. RE&DS refers to the City of Calgary Real Estate & Development Services business unit. Parks, Roads, Transportation Infrastructure, and Facilities Management are also City business units. CMLC refers to the Calgary Municipal Land Corporation, a wholly-owned subsidiary of the City of Calgary.

APPENDIX B – SOLAR CARPORT EXAMPLES



Figure B1. An architect's rendering of the solar carport installed in 2017 at the Simons location at Londonderry Mall in Edmonton, Alberta (Dodge, 2017, Figure 4).



Figure B2. A solar carport installation at the new regional Public Operations Centre, constructed in 2014 for the Regional Municipality of Wood Buffalo in Northern Alberta (Christian, 2014, Figure 1).



Figure B3. A solar carport installation at the Weeze Airport in North Rhine-Westphalia, Germany (Ola, 2016, Figure 2).

APPENDIX C – CPA SURFACE LOT BASIC FEASIBILITY ASSESSMENT

Table C1

Characteristics of CPA-managed surface lots owned by the City of Calgary that are outside of secondary network boundaries.

| <u>Lot</u> | <u>Address</u> | <u>Zoning</u> | <u>Stalls</u> | <u>Stewardship</u> |
|------------|-----------------------------------|---------------|---------------|--------------------|
| Lot 2 | 112 – 14 Ave. NW | C-COR2, R-C2 | 66 | CPA, RE&DS |
| Lot 10 | 816, 820 Edmonton Tr. NE | DC | 23 | CPA, TI |
| Lot 20 | 125, 203 – 14 St. NW | C-COR2 | 36 | CPA |
| Lot 21 | 344 – 14 St. NW | C-COR2 | 24 | RE&DS |
| Lot 23 | 1101 Memorial Dr. NW | S-R | 41 | Parks |
| Lot 37 | 1056 Memorial Dr. NW | M-C2 | 12 | Roads |
| Lot 43 | 880 – 11 St. SE, 1206 – 9 Ave. SE | DC | 30 | CPA |
| Lot 44 | 1301 – 9 Ave. SW | DC | 38 | CPA |
| Lot 57 | 1219 Kensington Rd. NW | C-COR1 | 26 | CPA |
| Lot 59 | 200 Memorial Dr. NW | S-R, S-UN | 179 | Parks |

Notes. Small power generation facilities are a discretionary use for parcels designated C-COR1, C-COR2 and M-C2, and a permitted use for parcels designated S-R and S-UN. RE&DS refers to the City's Real Estate and Development Services business unit. TI refers to the City's Transportation Infrastructure business unit.

APPENDIX D – LOT 59 SATELLITE IMAGES

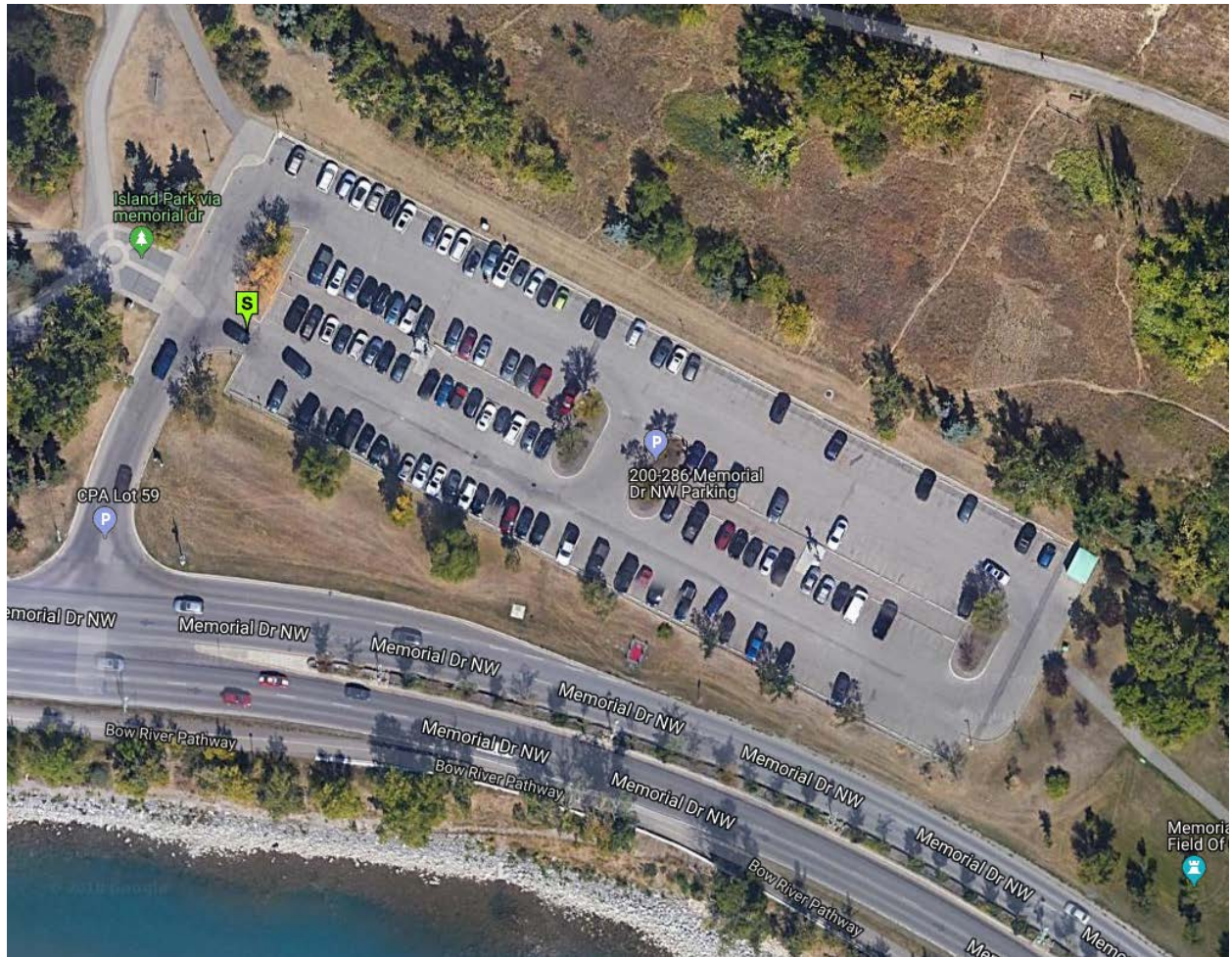


Figure D1. A satellite image of Lot 59 retrieved from Google Maps.

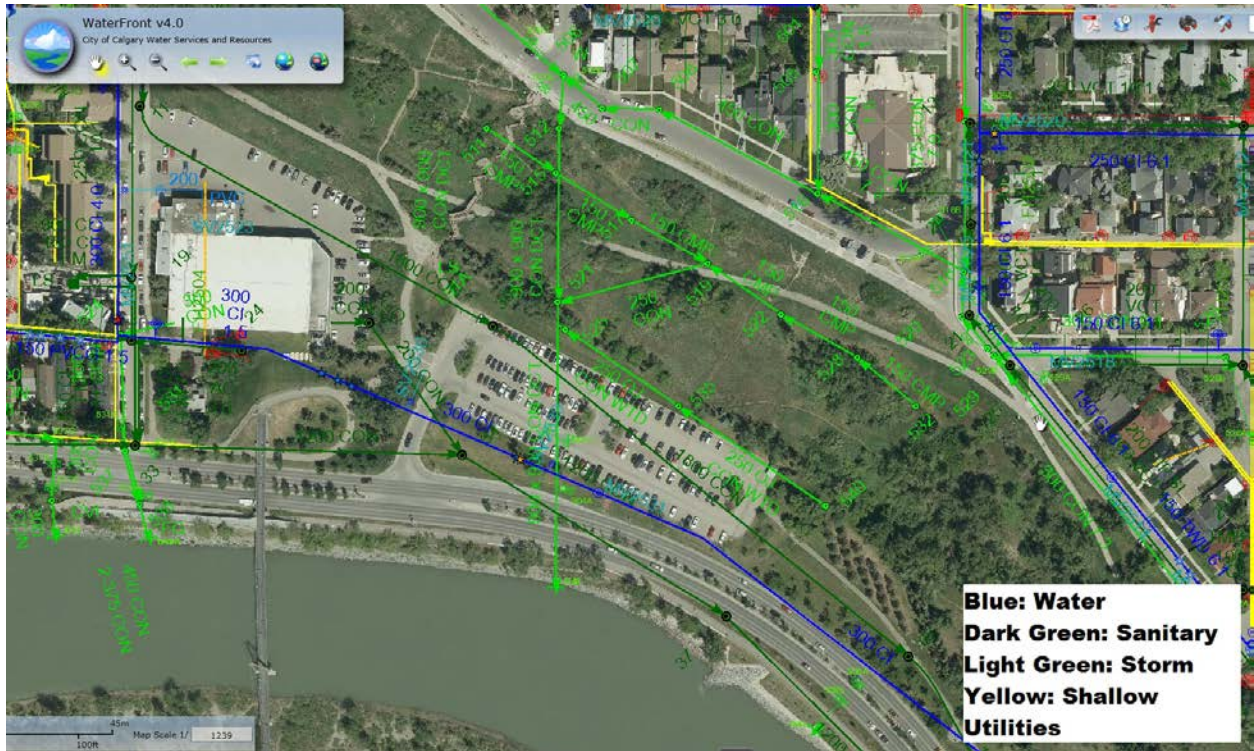


Figure D2. A satellite image of Lot 59 obtained from The City of Calgary Energy Management Office showing known utilities through the site.

APPENDIX E – COST-BENEFIT ANALYSIS PARAMETERS

Table E1

Parameters used in project cost-benefit analysis

| <u>Parameter</u> | <u>Value</u> |
|---|--------------|
| PV system size (parking stalls) | 76 |
| PV system nameplate capacity (kW) ¹ | 160 |
| PV system first year annual production (kWh) ¹ | 193,927 |
| PV system annual production capacity (system loss) ² | 0.99 |
| Lot 59 2017 annual electricity consumption (kWh) ³ | 4,231 |
| PV system first year surplus annual production (kWh) | 189,696 |
| PV system lifespan based on warranty term (years) ¹ | 25 |
| Lot 59 2017 delivery costs (including GST) (\$) ³ | 722.38 |
| Greenhouse gas emissions generated in Alberta (tonnes/kWh) ⁴ | 0.00079 |
| Social discount rate – base case (%) | 3.5 |
| Social discount rate – sensitivity analysis (low) (%) | 0.0 |
| Social discount rate – sensitivity analysis (medium) (%) | 2.5 |
| Social discount rate – sensitivity analysis (high) (%) | 7.0 |
| Calgary population ⁵ | 1,239,220 |
| Alberta population ⁵ | 4,067,175 |
| Canada population ⁵ | 35,151,728 |

Sources.

¹Data provided by ENMAX Solar.

²Alghamdi, Bajah & Wu. (2017). Assessment of large scale photovoltaic power generation from carport canopies.

³Lot 59 site data provided by the Calgary Parking Authority.

⁴National Energy Board. (2017b). Canada's renewable power landscape 2017, energy market analysis.

⁵Statistics Canada. (2017). Population and dwelling count highlight tables, 2016 census.

APPENDIX F – COST-BENEFIT ANALYSIS CALCULATIONS

Table F1

Net Present Value of Investment Per Stall, Scenario 1 – Low Electricity Prices, 0.0% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Total benefits | 0 | 147.69 | 138.60 | 143.57 | 124.56 | 127.02 | 128.46 | 125.17 | 124.03 | 121.51 | 117.44 | 115.93 | 112.42 | |
| Discounted Benefits | 0 | 147.69 | 138.60 | 143.57 | 124.56 | 127.02 | 128.46 | 125.17 | 124.03 | 121.51 | 117.44 | 115.93 | 112.42 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | 9,766.16 |
| Total benefits | 118.91 | 112.15 | 109.84 | 107.56 | 105.32 | 103.12 | 101.16 | 99.03 | 97.13 | 95.06 | 93.23 | 91.22 | 89.45 | |
| Discounted Benefits | 118.91 | 112.15 | 109.84 | 107.56 | 105.32 | 103.12 | 101.16 | 99.03 | 97.13 | 95.06 | 93.23 | 91.22 | 89.45 | 2,849.57 |
| | | | | | | | | | | | | | | NPV -6,916.59 |

Table F2

Net Present Value of Investment Per Stall, Scenario 2 – High Electricity Prices, 0.0% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Total benefits | 0 | 147.69 | 138.60 | 145.52 | 133.82 | 134.56 | 136.40 | 132.61 | 133.07 | 130.24 | 126.60 | 124.37 | 118.16 | |
| Discounted Benefits | 0 | 147.69 | 138.60 | 145.52 | 133.82 | 134.56 | 136.40 | 132.61 | 133.07 | 130.24 | 126.60 | 124.37 | 118.16 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | 9,766.16 |
| Total benefits | 124.59 | 118.92 | 117.04 | 115.12 | 113.29 | 111.49 | 109.71 | 107.96 | 106.18 | 104.49 | 103.02 | 101.37 | 99.69 | |
| Discounted Benefits | 124.59 | 118.92 | 117.04 | 115.12 | 113.29 | 111.49 | 109.71 | 107.96 | 106.18 | 104.49 | 103.02 | 101.37 | 99.69 | 3,034.50 |
| | | | | | | | | | | | | | | NPV |
| | | | | | | | | | | | | | | -6,731.67 |

Table F3

Net Present Value of Investment Per Stall, Scenario 1 – Low Electricity Prices, 2.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 215.86 | 0 | 0 | | |
| Total benefits | 0 | 147.69 | 138.60 | 143.57 | 124.56 | 127.02 | 128.46 | 125.17 | 124.03 | 121.51 | 117.44 | 115.93 | 112.42 | | |
| Discounted Benefits | 0 | 144.08 | 131.92 | 133.31 | 112.85 | 112.27 | 110.77 | 105.30 | 101.79 | 97.30 | 91.75 | 88.35 | 83.59 | | |
| | Year (continued) | | | | | | | | | | | | | Total | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | | |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 168.63 | 0 | 0 | 0 | 0 | 0 | 9,598.01 | |
| Total benefits | 118.91 | 112.15 | 109.84 | 107.56 | 105.32 | 103.12 | 101.16 | 99.03 | 97.13 | 95.06 | 93.23 | 91.22 | 89.45 | | |
| Discounted Benefits | 86.26 | 79.37 | 75.84 | 72.46 | 69.22 | 66.12 | 63.28 | 60.43 | 57.83 | 55.22 | 52.83 | 50.43 | 48.25 | 2,150.82 | |
| | | | | | | | | | | | | | | NPV | -7,447.19 |

Table F4

Net Present Value of Investment Per Stall, Scenario 2 – High Electricity Prices, 2.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 215.86 | 0 | 0 | |
| Total benefits | 0 | 147.69 | 138.60 | 145.52 | 133.82 | 134.56 | 136.40 | 132.61 | 133.07 | 130.24 | 126.60 | 124.37 | 118.16 | |
| Discounted Benefits | 0 | 144.08 | 131.92 | 135.13 | 121.23 | 118.93 | 117.62 | 111.56 | 109.22 | 104.29 | 98.90 | 94.79 | 87.86 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 168.63 | 0 | 0 | 0 | 0 | 0 | 9,598.01 |
| Total benefits | 124.59 | 118.92 | 117.04 | 115.12 | 113.29 | 111.49 | 109.71 | 107.96 | 106.18 | 104.49 | 103.02 | 101.37 | 99.69 | |
| Discounted Benefits | 90.38 | 84.17 | 80.81 | 77.55 | 74.45 | 71.48 | 68.63 | 65.89 | 63.22 | 60.69 | 58.38 | 56.04 | 53.77 | 2,280.98 |
| | | | | | | | | | | | | | | NPV |
| | | | | | | | | | | | | | | -7,317.03 |

Table F5

Net Present Value of Investment Per Stall, Scenario 1 – Low Electricity Prices, 3.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 195.89 | 0 | 0 | |
| Total benefits | 0 | 147.69 | 138.60 | 143.57 | 124.56 | 127.02 | 128.46 | 125.17 | 124.03 | 121.51 | 117.44 | 115.93 | 112.42 | |
| Discounted Benefits | 0 | 142.69 | 129.38 | 129.49 | 108.55 | 106.95 | 104.50 | 98.38 | 94.19 | 89.16 | 83.26 | 79.40 | 74.40 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 138.87 | 0 | 0 | 0 | 0 | 0 | 9,548.28 |
| Total benefits | 118.91 | 112.15 | 109.84 | 107.56 | 105.32 | 103.12 | 101.16 | 99.03 | 97.13 | 95.06 | 93.23 | 91.22 | 89.45 | |
| Discounted Benefits | 76.03 | 69.28 | 65.56 | 62.03 | 58.69 | 55.52 | 52.62 | 49.77 | 47.16 | 44.60 | 42.26 | 39.95 | 37.85 | 1,941.67 |
| | | | | | | | | | | | | | | NPV |
| | | | | | | | | | | | | | | -7,606.61 |

Table F6

Net Present Value of Investment Per Stall, Scenario 2 – High Electricity Prices, 3.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 195.89 | 0 | 0 | | |
| Total benefits | 0 | 147.69 | 138.60 | 145.52 | 133.82 | 134.56 | 136.40 | 132.61 | 133.07 | 130.24 | 126.60 | 124.37 | 118.16 | | |
| Discounted Benefits | 0 | 142.69 | 129.38 | 131.25 | 116.61 | 113.29 | 110.96 | 104.23 | 101.06 | 95.56 | 89.75 | 85.19 | 78.20 | | |
| | Year (continued) | | | | | | | | | | | | | Total | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total | |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 138.87 | 0 | 0 | 0 | 0 | 0 | 9,548.28 | |
| Total benefits | 124.59 | 118.92 | 117.04 | 115.12 | 113.29 | 111.49 | 109.71 | 107.96 | 106.18 | 104.49 | 103.02 | 101.37 | 99.69 | | |
| Discounted Benefits | 79.66 | 73.47 | 69.86 | 66.39 | 63.13 | 60.02 | 57.07 | 54.26 | 51.56 | 49.02 | 46.70 | 44.40 | 42.18 | 2,055.88 | |
| | | | | | | | | | | | | | | NPV | -7,492.40 |

Table F7

Net Present Value of Investment Per Stall, Scenario 1 – Low Electricity Prices, 7.0% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 140.46 | 0 | 0 | | |
| Total benefits | 0 | 147.69 | 138.60 | 143.57 | 124.56 | 127.02 | 128.46 | 125.17 | 124.03 | 121.51 | 117.44 | 115.93 | 112.42 | | |
| Discounted Benefits | 0 | 138.03 | 121.06 | 117.19 | 95.03 | 90.56 | 85.60 | 77.95 | 72.18 | 66.09 | 59.70 | 55.08 | 49.92 | | |
| | Year (continued) | | | | | | | | | | | | Total | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | | |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.41 | 0 | 0 | 0 | 0 | 0 | 9,425.40 | |
| Total benefits | 118.91 | 112.15 | 109.84 | 107.56 | 105.32 | 103.12 | 101.16 | 99.03 | 97.13 | 95.06 | 93.23 | 91.22 | 89.45 | | |
| Discounted Benefits | 49.34 | 43.49 | 39.81 | 36.43 | 33.34 | 30.51 | 27.97 | 25.59 | 23.46 | 21.46 | 19.67 | 17.98 | 16.48 | 1,413.93 | |
| | | | | | | | | | | | | | | NPV | -8,011.47 |

Table F8

Net Present Value of Investment Per Stall, Scenario 2 – High Electricity Prices, 7.0% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 140.46 | 0 | 0 | |
| Total benefits | 0 | 147.69 | 138.60 | 145.52 | 133.82 | 134.56 | 136.40 | 132.61 | 133.07 | 130.24 | 126.60 | 124.37 | 118.16 | |
| Discounted Benefits | 0 | 138.03 | 121.06 | 118.79 | 102.09 | 95.94 | 90.89 | 82.58 | 77.45 | 70.84 | 64.36 | 59.09 | 52.47 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.41 | 0 | 0 | 0 | 0 | 0 | 9,425.40 |
| Total benefits | 124.59 | 118.92 | 117.04 | 115.12 | 113.29 | 111.49 | 109.71 | 107.96 | 106.18 | 104.49 | 103.02 | 101.37 | 99.69 | |
| Discounted Benefits | 51.70 | 46.12 | 42.42 | 39.00 | 35.86 | 32.98 | 30.34 | 27.90 | 25.64 | 23.58 | 21.73 | 19.98 | 18.37 | 1,489.20 |
| | | | | | | | | | | | | | NPV | -7,936.20 |

Table F9

Net Present Value of Investment Per Stall (Agency Cost), Scenario 1 – Low Electricity Prices, 3.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,213.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 276.32 | 0.00 | 0.00 | |
| Discounted costs | 9,213.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 195.89 | 0.00 | 0.00 | |
| Total benefits | 2,193.70 | 147.69 | 138.60 | 143.57 | 124.56 | 127.02 | 128.46 | 125.17 | 124.03 | 121.51 | 117.44 | 115.93 | 112.42 | |
| Discounted Benefits | 2,193.70 | 142.69 | 129.38 | 129.49 | 108.55 | 106.95 | 104.50 | 98.38 | 94.19 | 89.16 | 83.26 | 79.40 | 74.40 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 276.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| Discounted costs | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 138.87 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9,548.28 |
| Total benefits | 118.91 | 112.15 | 109.84 | 107.56 | 105.32 | 103.12 | 101.16 | 99.03 | 97.13 | 95.06 | 93.23 | 91.22 | 89.45 | |
| Discounted Benefits | 76.03 | 69.28 | 65.56 | 62.03 | 58.69 | 55.52 | 52.62 | 49.77 | 47.16 | 44.60 | 42.26 | 39.95 | 37.85 | 4,135.36 |
| | | | | | | | | | | | | | | NPV |
| | | | | | | | | | | | | | | -5,412.92 |

Table F10

Net Present Value of Investment Per Stall (Agency Cost), Scenario 2 – High Electricity Prices, 3.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,213.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 195.89 | 0 | 0 | |
| Total benefits | 2,193.70 | 147.69 | 138.60 | 145.52 | 133.82 | 134.56 | 136.40 | 132.61 | 133.07 | 130.24 | 126.60 | 124.37 | 118.16 | |
| Discounted Benefits | 2,193.70 | 142.69 | 129.38 | 131.25 | 116.61 | 113.29 | 110.96 | 104.23 | 101.06 | 95.56 | 89.75 | 85.19 | 78.20 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 138.87 | 0 | 0 | 0 | 0 | 0 | 9,548.28 |
| Total benefits | 124.59 | 118.92 | 117.04 | 115.12 | 113.29 | 111.49 | 109.71 | 107.96 | 106.18 | 104.49 | 103.02 | 101.37 | 99.69 | |
| Discounted Benefits | 79.66 | 73.47 | 69.86 | 66.39 | 63.13 | 60.02 | 57.07 | 54.26 | 51.56 | 49.02 | 46.70 | 44.40 | 42.18 | 4,249.58 |
| | | | | | | | | | | | | | | NPV |
| | | | | | | | | | | | | | | -5,298.70 |

Table F11

Net Present Value of Investment Per Stall (Social Cost), Scenario 1 – Low Electricity Prices, 3.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,198.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,198.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 195.89 | 0 | 0 | |
| Total benefits | 1,525.30 | 288.96 | 304.03 | 332.65 | 336.81 | 361.95 | 385.60 | 404.05 | 424.19 | 442.50 | 458.82 | 477.24 | 493.24 | |
| Discounted Benefits | 1,525.30 | 279.19 | 283.81 | 300.03 | 293.51 | 304.75 | 313.69 | 317.58 | 322.13 | 324.68 | 325.26 | 326.88 | 326.42 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 138.87 | 0 | 0 | 0 | 0 | 0 | 9,532.81 |
| Total benefits | 518.81 | 530.71 | 546.65 | 562.22 | 577.42 | 592.27 | 606.97 | 621.11 | 635.11 | 648.57 | 661.91 | 674.71 | 687.39 | |
| Discounted Benefits | 331.73 | 327.86 | 326.29 | 324.23 | 321.74 | 318.85 | 315.72 | 312.15 | 308.39 | 304.28 | 300.03 | 295.49 | 290.87 | 9,320.89 |
| | | | | | | | | | | | | | | NPV |
| | | | | | | | | | | | | | | -211.92 |

Table F12

Net Present Value of Investment Per Stall (Social Cost), Scenario 2 – High Electricity Prices, 3.5% social discount rate (2018\$)

| | Year | | | | | | | | | | | | | |
|---------------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Total costs | 9,198.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | |
| Discounted costs | 9,198.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 195.89 | 0 | 0 | |
| Total benefits | 1,525.30 | 288.96 | 304.03 | 334.60 | 346.07 | 369.49 | 393.54 | 411.50 | 433.24 | 451.23 | 467.97 | 485.68 | 498.98 | |
| Discounted Benefits | 1,525.30 | 279.19 | 283.81 | 301.79 | 301.58 | 311.10 | 320.14 | 323.43 | 329.01 | 331.08 | 331.75 | 332.67 | 330.22 | |
| | Year (continued) | | | | | | | | | | | | | |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | Total |
| Total costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 276.32 | 0 | 0 | 0 | 0 | 0 | |
| Discounted costs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 138.87 | 0 | 0 | 0 | 0 | 0 | 9,532.81 |
| Total benefits | 524.49 | 537.49 | 553.85 | 569.78 | 585.39 | 600.63 | 615.51 | 630.04 | 644.16 | 658.00 | 671.69 | 684.86 | 697.63 | |
| Discounted Benefits | 335.36 | 332.05 | 330.59 | 328.59 | 326.18 | 323.36 | 320.16 | 316.64 | 312.79 | 308.70 | 304.47 | 299.94 | 295.20 | 9,435.10 |
| | | | | | | | | | | | | | | NPV |
| | | | | | | | | | | | | | | -97.71 |