Edmonton City Plan Scenarios

Climate Vulnerability Cost Assessment

1 November 2019

This technical study was initiated to inform the development of The City Plan. The technical studies were considered alongside public engagement, modelling and professional judgment to determine overall outcomes for The City Plan.

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1 Background to City Plan

Edmonton's City Plan is being developed with a target of doubling the population to two million people over several decades. This forward looking Plan needs to be assessed from the perspective of several fundamental choices related to population growth—for example, where will people live, where will people access services, and where will the new jobs be located.

The City Plan team is using a range of modelling tools to simulate the city-wide effects of how an increase of population could impact each of these choices. Modelling possible growth scenarios will help improve the City's understanding of what those choices might look like, as well as generate evidence on the positive and negative (monetary and non-monetary) consequences associated with various land use and transportation permutations.

The overall approach adopted by the City Plan team involves four steps:

1. Develop three "Evaluation Scenarios";
2. Model the Evaluation Scenarios and assess outcomes against a set of predetermined performance indicators;
3. Extract learning from the assessment of the Evaluation Scenarios to inform the development of the "Draft Recommended Land Use Concept"; and
4. Model and reassess the Draft Recommended Land Use Concept against the performance indicators and make changes as needed.

Three Evaluation Scenarios were developed by the City Plan team that illustrate the potential locations and intensity of growth for Edmonton to accommodate 2 million people. They are intended to have comparatively different growth patterns. They have been named the **Central City** (City I), **Node City** (City II) and the **Corridor City** (City III). Narratives have been developed to describe the three 'cities' and provide an overview of the built form, transportation, employment, green networks, and open space envisioned. The concept of nodes and corridors is represented at different scales and with contrasting purposes within each of the Evaluation Scenarios.

A Business-as-Usual (BAU) Scenario and a Business-as-Planned (BAP) Scenario have also been developed to (a) understand the financial implications of extrapolating current growth patterns into the future and (b) to provide a benchmark against which to assess the relative performance of the Evaluation Scenarios (at a high-level, or where technically feasible, on a per capita basis). The Evaluation Scenarios will also be compared to a current base year.

A description of each Evaluation Scenario, and the BAU, BAP, and Draft Recommended Land Use Concept scenarios is provided below:

Business-as-usual Scenario (BAU)

The BAU Scenario is based on a projection of existing development patterns and development trends. This scenario distributes future growth in the same places Edmonton has seen growth over the past 10 years. It also attempts to encompass the required infrastructure upgrades that will be required to sustain the BAU development trends.

Business-as-Planned Scenario (BAP)

The BAP Scenario assumes growth occurs according to the City's approved and strategic land use plans, including Area Structure Plans (and associated Neighbourhood Structure Plans) contained within the Plans in Effect. The BAP Scenario also contains plans for Area Restructure Plans, including infill redevelopments such as Blatchford, Bonnie Doon, and Mill Woods Town Centre. This scenario is more ambitious in terms of growth intensification than the BAU Scenario—in that more growth occurs through redevelopment of mature and developed areas of the City.

Central City (City I)

This scenario looks to concentrate employment and population within a specific boundary centred mainly around current downtown and mature areas. Policies would focus on achieving a strong central core that is supported by a large concentration of population and employment within the central core boundaries. Nodes and corridors are mainly located within the central core with strategic nodes located outside the central core boundary.

Node City (City II)

This scenario will look to attract more people to reside in the central core and distribute new jobs to other areas of the City. Policies will work to ensure the city develops into a community of communities that are spatially bounded by 15 different City District boundaries. The Districts and a tiered network of activity centres (nodes) are the base structural elements of this scenario. Corridors are also present within this scenario; however, their location is more strategic in nature. Overall, they play a supportive/secondary role.

Corridor City (City III)

This scenario redistributes population and employment throughout the city along corridors, with less concentration in nodes. There is a heavy focus on rebuilding, repurposing or reclaiming underutilized land (commercial, institutional, industrial) to distribute medium intensity development and green spaces to all parts of the city. Policies would pursue achieving more equitable and spatially distributed access to services, jobs and housing by emphasizing high density corridors. Nodes still exist within this scenario; however, as with City II, their location is more strategic, and they play a supportive/secondary role.

Draft Recommended Land Use Concept

The Draft Recommended Land Use Concept (henceforth referred to as the "Recommended Concept") spatially provides the fundamental link between transportation, growth, employment and ecological networks. The distribution of people and jobs is based on learnings from the Evaluation Scenarios, technical studies, outcomes from modelling, professional judgement and engagement with stakeholders. The Recommended Concept incorporates elements of all three Evaluation Scenarios, including concentrating future growth within a network of nodes and corridors, and enabling increased density—particularly, in the core of the city. The Recommended Concept also includes an evolved mass transit network that incorporates and builds on the existing and future LRT network to provide a city-wide efficient system of public transport. As major destinations for people and jobs, primary nodes and corridors will be connected via higher-order transit service coupled with an emphasis on local walkability and cycling connectivity.

2 Climate vulnerability and risk cost assessment

In 2018 the City of Edmonton released *Climate Resilient Edmonton: Adaptation Strategy and Action Plan*. This document outlines a pathway towards climate resilience for Edmonton—i.e., to better prepare for, respond to, and recover from the anticipated impacts of climate change. It is complementary to the *Community Energy Transition Strategy*, which aims to reduce greenhouse gas emissions in Edmonton. As part of the evidence gathering process to inform *Climate Resilient Edmonton: Adaptation Strategy and Action Plan*, an Edmonton-specific vulnerability and risk assessment was conducted, which measured potential risks and opportunities associated with current and future climate conditions in Edmonton. This included analyses of expected economic (damage) costs for Edmonton—estimated to amount to about $18.2 billion (2016 dollars) annually by the end of the century. The purpose of this document is to extend the analysis, where possible, to:

- First, the Evaluation Scenarios to determine the relative climate-related costs arising under each scenario, as well as relative to the BAU Scenario; and
- Second, the Draft Recommended Land Use Concept to determine the relative climate-related costs arising under this scenario relative to the BAU Scenario.

2.1 Climate change in Edmonton

Climatic conditions in Edmonton are changing. Mean annual temperature has increased at a rate of 0.17°C per decade since 1917—that is over twice the global average. The rate of warming has accelerated over the last 50 years to 0.35°C per decade. The observed rate of warming in the winter months has been more pronounced than during the summer.

Looking to the future, Edmonton's climate is projected to change further. Anticipated changes in Edmonton's climate include:

- **Warmer temperatures**: Mean temperatures are projected to increase in all seasons, with the largest temperature increase projected for the winter months (December to February).
- **Increased precipitation**: Mean precipitation is projected to increase significantly in the spring season, and modestly in the winter and fall seasons; projected changes in summer precipitation are negligible.
- **Hotter drier summers**: Substantial increases in temperature, coupled with essentially no change in summer precipitation, and significant evapotranspiration, will result in hotter, drier summers.
- **Warmer wetter winters**: Both mean winter temperature and mean winter precipitation are projected to increase significantly, leading to warmer wetter winters.
- **More extreme precipitation**: Warming temperatures increase the water holding capacity of the atmosphere, which supply storms, resulting in more intense rainfall events and ultimately to flooding.
- **Extreme weather events**: Increasing frequency, and in some cases severity, of extreme weather events such as windstorms, lightning, freezing rain and heavy snow.

These changes will have a range of consequences for Edmonton's buildings, infrastructure, municipal services, public health & safety, natural environment, economy and quality of life. The severity and likelihood of a selection of future climate-related consequences for Edmonton were evaluated through a vulnerability and risk assessment (VRA), which also included analyses of associated economic costs (as mentioned above). Climate-related risks and associated costs were measured for three impact pathways, for 17 climate stressors (or 'hazards') and for 20 asset and service areas of the city (see Box 1). In addition, the impact of gradual climate change for projected space heating and cooling demand in Edmonton was quantified as part of the assessment.

Box 1: Scope of Edmonton's vulnerability and risk assessment (VRA)

The impact pathways considered were: direct physical damage to the exposed 'asset' (man-made, natural, people); indirect service losses resulting from damage to that exposed 'asset', where relevant; and direct service losses resulting from exposure of a vulnerable service flow to climate hazards irrespective of damage to the 'asset' which provides that service.

The climate hazards considered were: extreme heat, urban flooding, timing of frost free season, wildland-urban interface fire, drought, low flow in river, extreme cold, freeze thaw cycles, heavy snow, rain on snow, freezing rain, blizzard, river flooding, high winds, hail, lightning strikes and tornado.

Assets and services considered, included, for example: residential buildings, commercial premises, water and sanitation infrastructure, electricity infrastructure, people, ecosystems, urban forests, road transportation and LRT.

Damage/loss functions and monetary information from the suite of models used for the VRA have been used by this assessment to evaluate climate-related economic costs for elements of the City Plan scenarios, for which compatible data is available. Specifically, it was possible to estimate climate-related economic costs for residential and non-residential buildings, space heating and cooling demand, managed natural sites, terrestrial and aquatic habitat, and road transportation. Impacts of climate change on air quality (ground-level ozone) and human health have been assessed qualitatively. The results for each area are summarized below; first for the Evaluation Scenarios, and second, for the Recommended Concept. Note that all reported costs are in 2016 constant dollars. Furthermore, all costs are expected (probability adjusted) annual averages for the year 2065.

Consistent with the climate change VRA, the analysis is based on climate projections for Edmonton under Representative Concentration Pathway (RCP) 8.5 (see Box 2). The VRA sought to characterize the most problematic climate-related risks that could potentially affect Edmonton this century, in the absence of new adaptation strategies. Such significant risks are best identified using RCP 8.5—the high emissions scenario. Moreover, judicious assessments of climate-related risks should explicitly consider uncertainties. Basing the VRA on the high emissions scenario helps to account for uncertainty associated with atmospheric concentrations of GHGs as it encompasses projected climate changes under the other RCPs.

Box 2: Representative Concentration Pathways

Scenarios have long been used in climate research to analyse futures in which outcomes are uncertain. One of the largest uncertainties about how much the planet will warm in the coming decades has nothing to do with the physics of climatology, but is instead related to demographic, economic, resource, policy and technological factors that will influence how much greenhouse gases (GHGs) will be emitted globally in the future. In response to this uncertainty, scenarios have been developed to generate projections of climate change in response to different future emissions pathways—these scenarios are known as Representative Concentrations Pathways (or RCPs).

RCPs are time and space dependent trajectories of concentrations of GHGs and air pollutants from human activities. They provide a quantitative description of GHG concentrations in the atmosphere over time and their radiative forcing in 2100. Radiative forcing is the additional energy taken up by the Earth’s climate system due to the enhanced greenhouse effect; as the radiative forcing increases, the global temperature rises. The word “representative” signifies that each RCP provides only one of many possible scenarios that could lead to a specific level of radiative forcing. In total, there are four RCPs that lead to radiative forcing levels of 8.5, 6.0, 4.5 and 2.6 Watts per m2, by the end of the century. The four pathways are aptly labelled: RCP 8.5, RCP 6.0, RCP 4.5 and RCP 2.6.

RCP 8.5 is the relatively high-emissions scenario, consistent with a future with no additional policy changes to reduce GHG emissions. It is aligned broadly with a Business-As-Usual scenario. RCP 2.6 is broadly in line with the Paris Agreement’s stated goal to limit global temperature increases to +2°C above pre-industrial levels.

2.2 Adapting to climate change impacts

Adapting to the impacts of climate change involves taking deliberate actions that: (a) reduce potential risks and negative consequences; or (b) exploit potential opportunities. In terms of mitigating harm, generic adaptation actions can include:

- Offsetting losses by sharing or spreading risks among the wider population (e.g., through insurance or disaster assistance programs).
- Modifying the threat by implementing measures to control or contain climate-related hazards (e.g., enhancing existing or building new flood defences).

- Avoiding or reducing exposure to climate risks (e.g., changing the location of man-made and natural assets and infrastructure, people, services, etc. via planning or implementing early warning systems).
- Reducing the sensitivity of exposed assets and infrastructure, people, services, etc. to harm from climate risks (e.g., enhanced design standards and building code, improved emergency planning or planting drought resistant trees).
- Conducting research to improve understanding of the relationship between climate change and potential risks or to investigate new adaptation policies and programs.
- Encouraging behavioural change through education and information provision (e.g., dissemination of hazard maps, voluntary or mandatory risk disclosure or public information campaigns).

The City Plan scenarios fundamentally define where people will live, work and access services. As a result, they will directly influence the future costs of climate change for Edmonton by changing the *quantity* of man-made and natural assets and infrastructure, people, services, etc. (collectively coined the “stock-at-risk”) exposed to climate hazards of a given intensity. Not only does the total “stock-at-risk” change across the City Plan scenarios, but so does its *location* and *composition*. Location is important as some areas of the city are more susceptible than others to, for example, stormwater flooding and wildland-interface fires. Furthermore, buildings in areas with a higher density of trees will be more vulnerable to damage from strong winds, freezing rain and heavy snow events, other things being equal. Composition of the “stock-at-risk” is also an important determinant of cost as specific building types (e.g., moveable homes) are more susceptible to damage from specific hazards (e.g., urban flooding) than other building types (e.g., multi-storey apartments). In summary, the City Plan scenarios will affect the costs of climate change for Edmonton by influencing the *quantity*, *location* and *composition* of the stock-at-risk. The results below capture the net effect of changes in all three of these factors. Untangling the contribution of each determinant to the overall net effect is beyond the scope of this project.

In general, land-use planning is an important adaptation measure habitually included in climate change adaptation strategies, since it simultaneously and cost-efficiently mitigates the impacts of multiple climate hazards across a range of vulnerable “assets and services”. Estimated reductions in climate change costs delivered by the City Plan scenarios—as modeled in this project—are a key input to economic analyses of the portfolio of actions included in *Climate Resilient Edmonton: Adaptation Strategy and Action Plan*. Mainly, they indicate the magnitude of climate-related risk reductions required from other adaptation actions to achieve an acceptable level risk and residual costs.

3. Results

Estimated climate-related economic costs are presented below for residential and non-residential buildings, projected space heating and cooling demand, managed natural sites, terrestrial and aquatic habitat, and road transportation. Results are presented, first, for the Evaluation Scenarios compared to the BAU or BAP Scenario, and second, for the Recommended Concept compared to the BAU Scenario.

The potential contribution of each scenario and the Recommended Concept to climate-enhanced air quality and adverse health outcomes is also assessed.

3.1 Residential buildings

Scope of the analysis:

- Climate impacts considered: All 17 climate hazards (see Box 1).
- Impact pathways considered: Direct physical damage and indirect service loss (see Box 1).
- Costs included: Repair and replacement costs of buildings, replacement cost of building contents, relocation costs for temporary accommodation and disruption (for those properties requiring evacuation).
- Key data from City Plan team: projections of the number of single-family, multi-family, apartment and other dwellings for 2065, by neighbourhood.

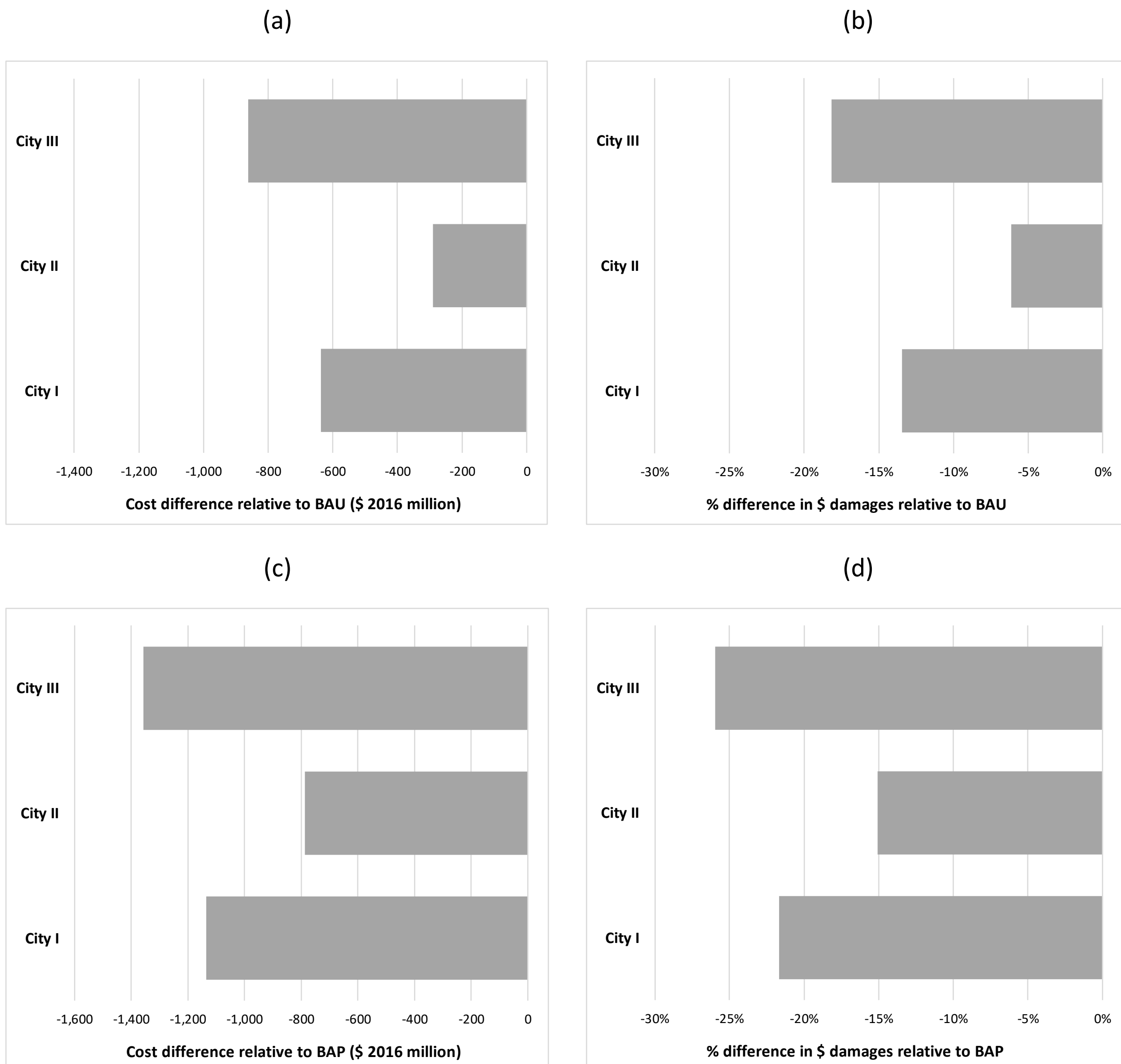
3.1.1 Evaluation Scenarios

Figure 1 shows the difference—in dollar terms and as a % difference—between projected climate-related costs for all residential buildings under each Evaluation Scenario (City I, City II and City III) relative to the BAU Scenario (panels a and b) and relative to the BAP scenario (panels c and d). The results of all Evaluation Scenarios are negative, suggesting costs are less under these scenarios than either the BAU or BAP Scenarios. Fundamentally, there are less buildings under the Evaluation Scenarios and thus fewer units exposed to climate hazards. The relative location and composition of the residential building stock under the Evaluation Scenarios also reduces vulnerability to harm—e.g., with densification fewer buildings are exposed to wildland interface fires in new developments on the periphery of the city (recall Section 2.2).[1]

Compared with both the BAU and BAP Scenarios the cost difference (saving) is greatest under **City III**. The relative *quantity*, *location* and *composition* of the residential building stock under City III results in an 18.2% and 25.9% reduction in damages relative to the BAU Scenario and BAP Scenario, respectively.

[1] Though not monetized in this project, less utility and other infrastructure is exposed to climate hazards generally under the Evaluation Scenarios, as well as to certain hazards to which new developments on the City fringe are more vulnerable, like wildland interface fires.

Figure 1: Results for Evaluation Scenarios for residential buildings

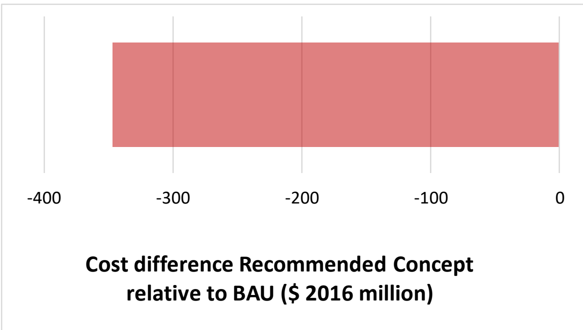


3.1.2 Draft Recommended Land-use Concept

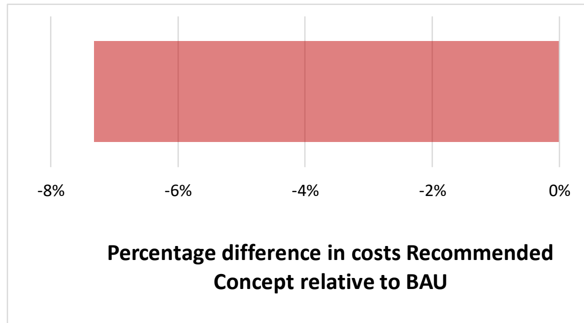
Figure 2 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected climate-related costs for residential buildings under the Recommended Concept and the BAU Scenario. The results are negative, suggesting climate-related economic costs are reduced by roughly $347 million (or 7.3%) in 2065 under the Recommended Concept compared with the BAU Scenario.

Figure 2: Results for Draft Recommended Land-use Concept for residential buildings

(a)



(b)



3.2 Non-residential buildings

Scope of the analysis:

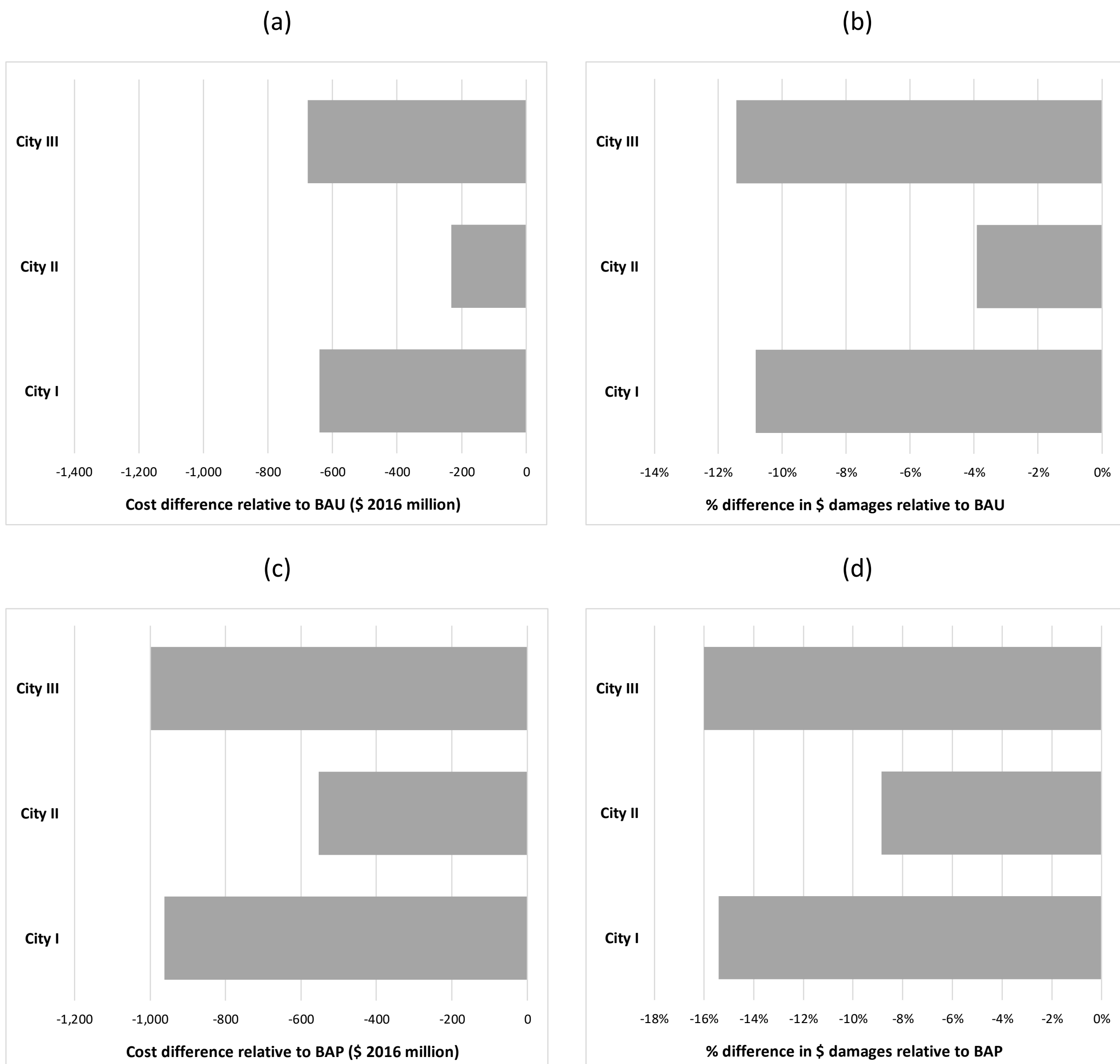
- Climate impacts considered: All 17 climate hazards (see Box 1).
- Impact pathways considered: Direct physical damage and indirect service loss (see Box 1).
- Costs included: Repair and replacement costs of buildings, replacement cost of building contents, relocation costs for temporary accommodation and disruption (for those properties requiring evacuation), foregone income from lost output.
- Key data from City Plan team: projections of the area of non-residential buildings and “commercial / institutional” land use (by neighbourhood) for 2065.

3.2.1 Evaluation Scenarios

Figure 3 shows the difference—in dollar terms and as a % difference—between projected climate-related costs for all non-residential (commercial and institutional) buildings under each Evaluation Scenario (City I, City II and City III) relative to the BAU Scenario (panels a and b) and relative to the BAP Scenario (panels c and d). The results of all Evaluation Scenarios are negative, suggesting costs are less under these scenarios than either the BAU or BAP Scenarios. As with residential buildings, there are less buildings under the Evaluation Scenarios and therefore fewer units exposed to climate hazards. Also, like residential buildings, the location of development is a contributing factor. Note that the available data did not differentiate between non-residential building types, so the composition of the building stock as a determinant of risk was not considered.

Relative to both the BAU and BAP Scenarios the cost difference (saving) is marginally greatest under **City III**. The relative *quantity* and *location* of the non-residential building stock under City III results in an 11.5% and 16.0% reduction in damages relative to the BAU Scenario and BAP Scenario, respectively.

Figure 3: Results for Evaluation Scenarios for non-residential buildings

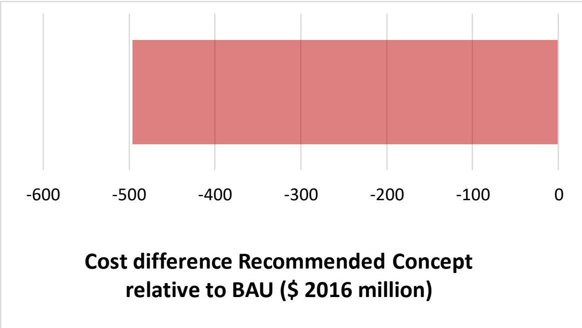


3.2.2 Draft Recommended Land-use Concept

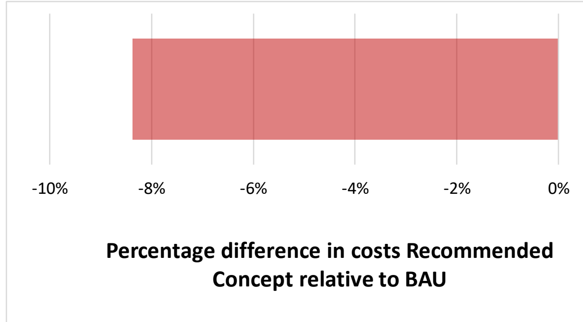
Figure 4 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected climate-related costs for non-residential buildings under the Recommended Concept and the BAU Scenario. The results are negative, suggesting climate-related economic costs are reduced by about $496 million (or 8.4%) in 2065 under the Recommended Concept compared with the BAU Scenario.

Figure 4: Results for Draft Recommended Land-use Concept for non-residential buildings

(a)



(b)



3.3 Space heating and cooling

Scope of the analysis:

- Climate impacts considered: Projected Heating Degree Days and Cooling Degree Days (change in degree days relative to 1961-1990 norm for Edmonton).[2]
- Impact pathways considered: Direct service loss (in this case, a net increase in home energy costs).
- Costs included: Net cost of electricity and natural gas consumption for space heating and space cooling in residential and non-residential sectors.
- Key data from City Plan team: projections of electricity and natural gas consumption by residential and non-residential sectors in 2061 and 2066, from which values for 2065 were interpolated.

3.3.1 Evaluation Scenarios

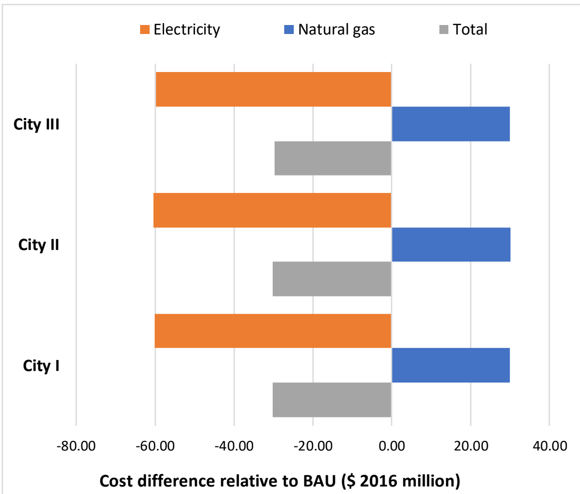
Figure 5 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected climate-related cost impacts on residential and non-residential space heating and space cooling demand under each Evaluation Scenario (City I, City II and City III) and the BAU Scenario (panels b and c). The results of all Evaluation Scenarios are negative, suggesting the impact of climate change on space heating and space cooling costs is less under these scenarios than the BAU Scenario. Note that in all scenarios, including the BAU Scenario, net energy costs are higher with climate change—i.e., increases in expenditures on space cooling exceed decreases in expenditures on space heating. The

[2] Heating Degree Days (HDD) is an index of the annual sum of daily mean temperatures that are less than 18°C. For example, a single day with a mean temperature of 14°C would contribute four degree days to the annual sum. This index provides a measure of energy demand to heat buildings. Cooling Degree Days (CDD) is an index of the annual sum of daily mean temperatures that exceed 18°C. For example, a single day with a mean temperature of 24°C would contribute four degree days to the annual sum. This index provides a measure of energy demand to cool buildings.

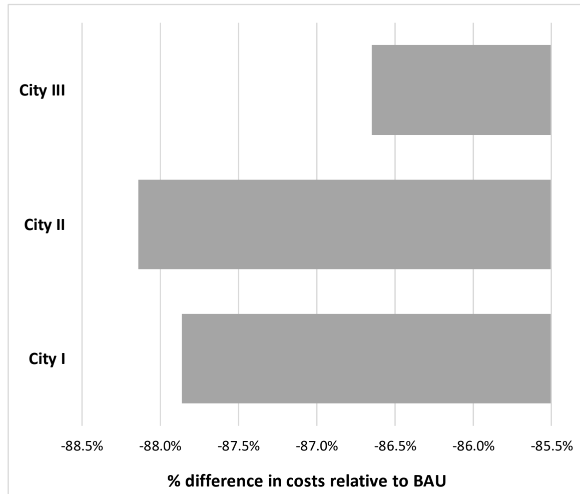
increase in net energy costs is simply less under the Evaluation Scenarios (+$4.1 to +$4.9 million) compared with the BAU Scenario (+$34.3 million); hence, the observed savings under the Evaluation Scenarios. Relative to the BAU Scenario the cost difference (saving) is marginally higher under **City II** (0.3 percentage points relative to City I, the next best performing Evaluation Scenario).

Figure 5: Results for Evaluation Scenarios for space heating and cooling demand

(a)



(b)

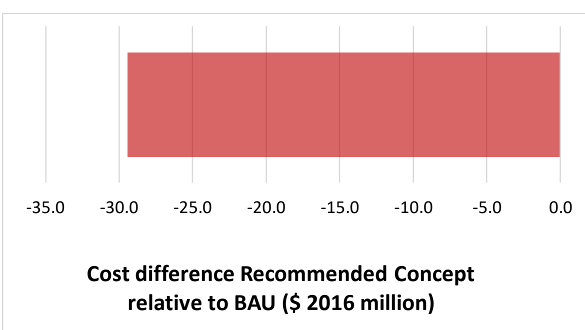


3.3.2 Draft Recommended Land-use Concept

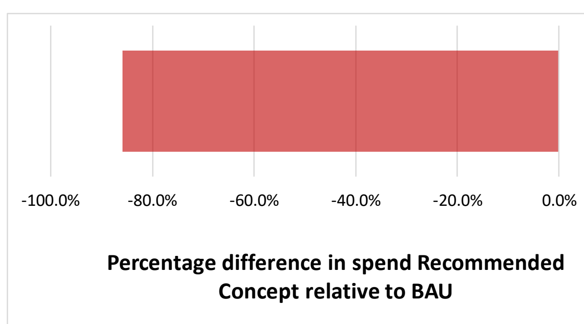
Figure 6 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected changes in expenditure on residential and non-residential space heating and space cooling demand attributable to climate change under the Recommended Concept relative to the BAU Scenario. The results are negative, suggesting climate-induced increases in energy expenditures are reduced by about $29 million (or 86%) in 2065 under the Recommended Concept compared with the BAU Scenario.

Figure 6: Results for Draft Recommended Land-use Concept for space heating and cooling demand

(a)



(b)



3.4 Natural environment

Scope of the analysis:

- Climate impacts considered: All 17 climate hazards.
- Impact pathways considered: Direct physical damage, indirect service loss.[3]
- Costs included: Repair and replacement costs for damage to managed natural sites and the social costs (forgone willingness-to-pay) associated with loss of ecosystem services for terrestrial and aquatic habitat.
- Key data from City Plan team: projections of different land uses in 2065, by neighbourhood.[4]

Consistent with Edmonton's climate change VRA, separate analyses are conducted for the impact of climate change on:

- Managed natural areas; and
- The provision of ecosystem services by terrestrial and aquatic habitat with ecological value.

The former case considers changes to maintenance and replacement costs; the latter case considers individual's valuations of changes in the provision of ecosystem services.

3.4.1 Evaluation Scenarios: Managed natural areas

Figure 7 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected climate-related costs for managed natural sites under each Evaluation Scenario (City I, City II and City III) relative to the BAU Scenario. The results of all Evaluation Scenarios are positive in total, suggesting aggregate repair and replacement costs are higher under the Evaluation Scenarios than the BAU scenario. This is because the increase in managed aquatic areas more than offsets the decrease in managed terrestrial areas under the Evaluation Scenarios in contrast to the BAU Scenario. It is important to recognize, however, that the additional climate-related costs of maintaining a net increase in managed natural areas must be weighed against the wide ranging social benefits the additional areas

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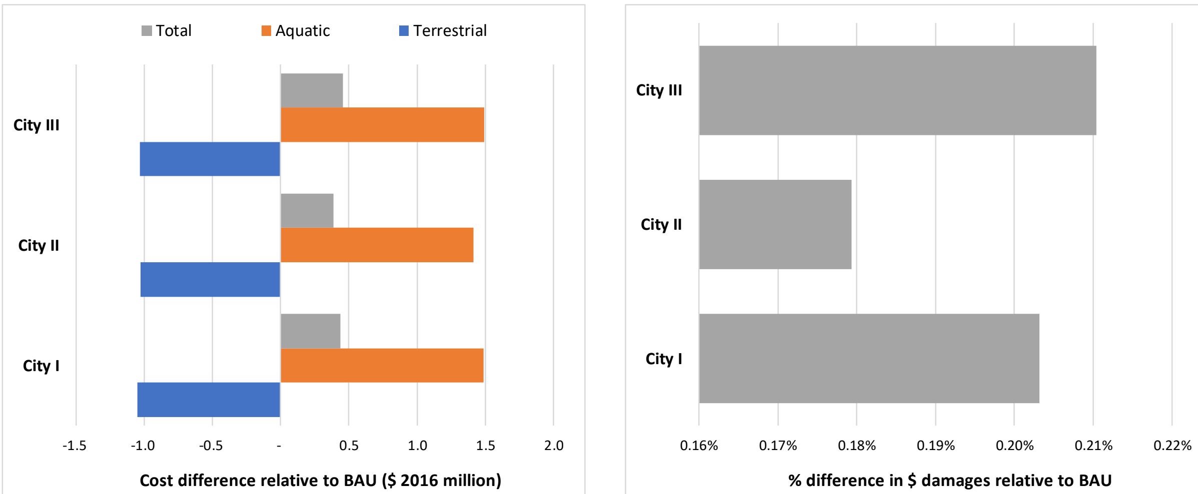
[3] In this case, service loss refers to impairment of the provision of ecosystem services by natural sites in Edmonton, such a habitat services (e.g., refuge and nursery services for plants and animals, the maintenance of biodiversity, etc.), regulatory services (e.g., natural control of water flows and quality, climate, soil erosion and formation, etc.) and cultural services (e.g., aesthetics, recreation, etc.). These service flows, which have value to people, are sensitive to changes in mean and extreme climate conditions.

[4] Aquatic areas include "wetland" and "open water" land use. Terrestrial areas include all other land uses. The proportion of all terrestrial areas that have positive ecological value, by neighbourhood—and thus are susceptible to impairment of ecosystem services due to climate change—is based on Edmonton's VRA. This is a sub-set of all terrestrial areas and excludes land uses such as "maintained trails", "residential development", "commercial development", "transportation surfaces", etc.

provide (see footnote 2). Relative to the BAU Scenario the cost difference (additional repair and replacement cost) is lowest under **City II**.

Figure 7: Results for Evaluation Scenarios for managed natural areas

(a) (b)

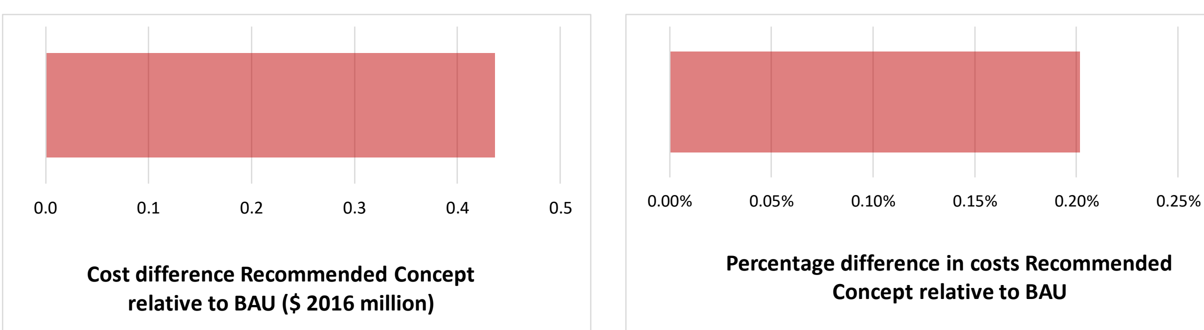


3.4.2 Draft Recommended Land-use Concept: Managed natural areas

Figure 8 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected changes in repair and replacement costs of managed natural areas in Edmonton attributable to climate change under the Recommended Concept relative to the BAU Scenario. The results are positive, suggesting climate-related economic costs are higher by roughly $0.5 million (or 0.2%) in 2065 under the Recommended Concept compared with the BAU Scenario. However, bearing in mind the above caveat, the overall net social benefit generated by a net increase in natural areas under the Recommended Concept may be higher relative to the BAU Scenario.

Figure 8: Results for Draft Recommended Land-use Concept for managed natural areas

(a) (b)

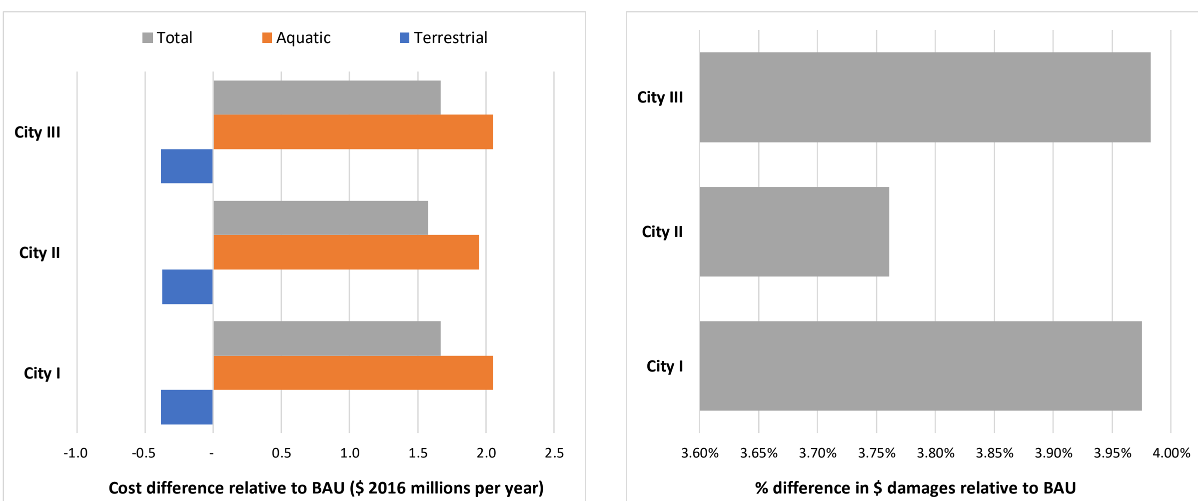


3.4.3 Evaluation Scenarios: Ecosystem services

Figure 9 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected climate-related costs for terrestrial and aquatic habitat with positive ecological value under each Evaluation Scenario (City I, City II and City III) relative to the BAU Scenario. The results of all Evaluation Scenarios are positive in total, suggesting aggregate costs are higher under the Evaluation Scenarios than the BAU Scenario. As explained above, this is partly because the increase in managed aquatic areas more than offsets the decrease in managed terrestrial areas under the Evaluation Scenarios in contrast to the BAU Scenario and partly because the social value (i.e., individuals' willingness-to-pay for the provision of associated ecosystem services) of wetlands is much greater than urban terrestrial habitat. Again, the additional climate-related costs of the net increase in habitat providing ecosystem services must be weighed against the wide ranging social benefits they provide that are not eroded by climate change. Relative to the BAU Scenario the cost difference (additional cost) is lowest under **City II** (bearing in mind the above caveat, the overall net social benefit of the other Evaluation Scenarios may be higher).

Figure 9: Results for Evaluation Scenarios for ecosystem services

(a) (b)



3.4.4 Draft Recommended Land-use Concept: Ecosystem services

Figure 10 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected costs of climate change on the provision of ecosystem services by terrestrial and aquatic habitat under the Recommended Concept relative to the BAU Scenario. The results are positive, suggesting climate-related costs are higher by roughly $1.7 million (or 4.1%) in 2065 under the Recommended Concept compared with the BAU Scenario. However, the overall net social benefit generated by a net increase in habitat providing ecosystem services under the Recommended Concept may be higher relative to the BAU Scenario.

Figure 10: Results for Draft Recommended Land-use Concept for ecosystem services

(a) (b)

3.5 Road transportation

Scope of the analysis:

- Climate impacts considered: All 17 climate hazards.
- Impact pathways considered: Direct physical damage, indirect (road transport) service loss and direct (road transport) service loss.
- Costs included: Repair and replacement costs of damaged roads and the social cost (forgone willingness-to-pay) of disrupted passenger trips and commercial trips.
- Key data from City Plan team: projections of the length of roads and passenger and freight vehicle kilometres travelled (VKT) in 2065.

3.5.1 Evaluation Scenarios

Figure 11 shows the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected climate-related costs for road infrastructure under each Evaluation Scenario (City I, City II and City III) and the BAU Scenario. The same information for disruption to road transport services (passenger plus freight) is shown in Figure 12. In both cases, the results of all Evaluation Scenarios are negative, suggesting costs are less under these scenarios than the BAU Scenario. Basically, there are less roads and associated infrastructure and fewer VKT under the Evaluation Scenarios, and thus less units exposed to climate hazards. Relative to the BAU Scenario the cost difference (saving) is greatest under **City I**.

Figure 11: Results for Evaluation Scenarios for damage to road infrastructure

(a) (b)

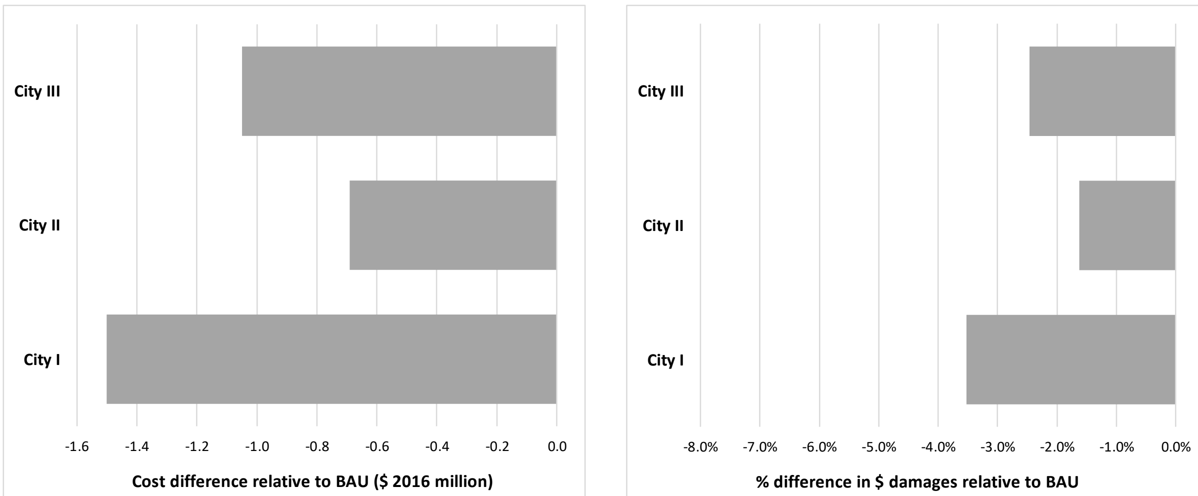
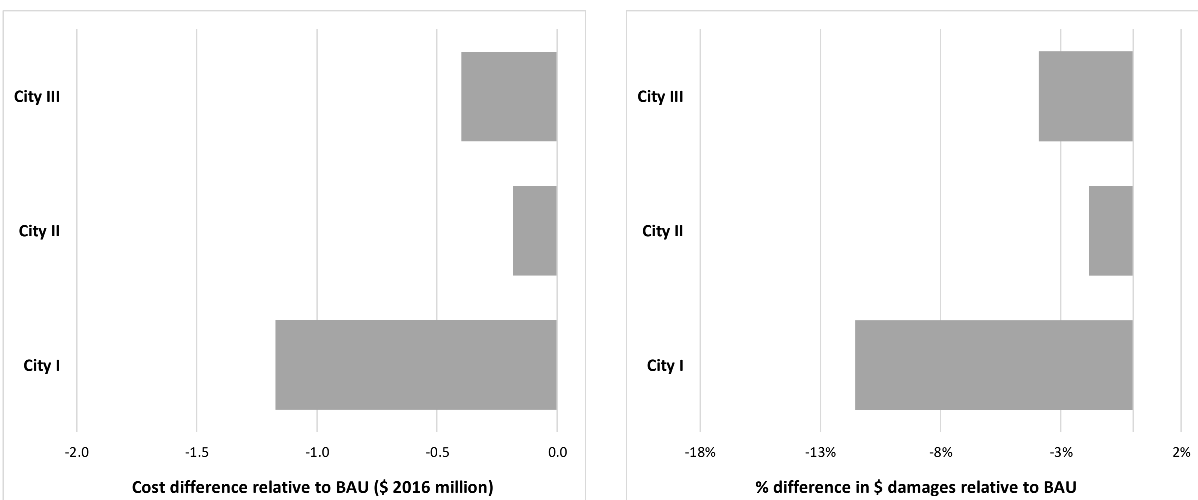


Figure 12: Results for Evaluation Scenarios for road transport services

(a) (b)



3.5.2 Draft Recommended Land-use Concept

Figure 13 and Figure 14 show the difference—in dollar terms (panel a) and as a % difference (panel b)—between projected climate-related costs for road infrastructure and road transport services, respectively, under the Recommended Concept relative to the BAU Scenario. In both cases, the results are negative, suggesting climate-related economic costs are reduced under the Recommended Concept compared with the BAU Scenario. Climate-related damages to road infrastructure are roughly $3.2 million (or 7.5%) lower under the Recommended Concept. A comparison with Figure 11 shows that these savings are larger than those estimated for City I—the best performing Evaluation Scenario. This is because the size of the road network (in terms of lane-kilometres) under the Recommended Concept is 4.1% smaller than for City I. Losses from disruption to road transport services due to climate change are about $0.5 million (or 5.4%) lower under the Recommended Concept compared with the BAU Scenario. However, the Recommended Concept does not perform as well as City I (compare Figure 14 with Figure 12) as total VKT are about 7% higher.

Figure 13: Results for Draft Recommended Land-use Concept for road transport infrastructure

(a) (b)

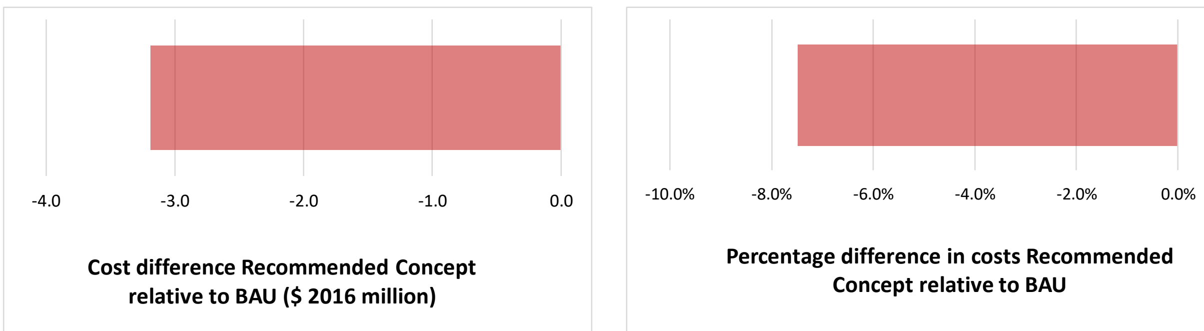


Figure 14: Results for Draft Recommended Land-use Concept for road transport services

(a) (b)

3.6 Air quality and climate change

Emissions of non-methane volatile organic compounds (NMVOCs), nitrogen oxides, carbon monoxide and methane contribute to the formation of ground-level (tropospheric) ozone. Tropospheric ozone can have adverse effects on human health and ecosystems.[5] High concentrations adversely affect the human

[5] EPA, 2013: Integrated Science Assessment for Ozone and Related Photochemical Oxidants. EPA 600/R-10/076F. U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, Research Triangle Park, NC, 1251 pp. EPA, 2014: Health Risk and Exposure Assessment for Ozone: Final Report. EPA-452/R-14-

respiratory and cardiovascular system and there is evidence that long-term exposure accelerates the decline in lung function with age and may impair the development of lung function.[6] Some people are more vulnerable to high concentrations than others, with the worst effects generally seen in children, asthmatics and the elderly.[7] High concentrations of tropospheric ozone in the environment are harmful to crops and trees, decreasing yields, causing leaf damage and reducing resistance to disease.[8] These adverse impacts are mainly a problem during the summer months.[9]

Climate change is expected to increase future ozone concentrations due to changes in meteorological conditions (mainly higher temperatures in summer), as well as due to increased emissions of specific ozone precursors (increased biogenic emissions of VOC and NO) and emissions from wildfires (which are expected to increase in frequency).[10]

3.6.1 Evaluation Scenarios

All else being equal, the impact of climate change on ozone-related mortality and morbidity health effects in Edmonton will be more severe under City Plans that result in the emission of more ozone-precursors. Figure 15 shows the *normalized* emissions of three ozone pre-cursors (NOx, CO and NMHC) from transport (tail-pipe and electricity generation) emissions for each Evaluation Scenario and the BAU and BAP Scenarios. Note that emissions from a deliberate shift towards increased use of personal electric vehicles are not included in the data; this will affect the results to the extent that the shift differs across the scenarios considered.

A value of 1.0 in Figure 15 indicates the best performing scenario (i.e., the one that emits the least ozone pre-cursors); all other scenarios are compared with this one. Hence, the impact of climate change on ozone-related mortality and morbidity health effects in Edmonton are expected to be lowest under **City I** and highest under the BAP, all else being equal.

3.6.2 Draft Recommended Land-use Concept

Figure 15 also shows the relative performance of the Recommended Concept. It performs better than City II and City III, but not as well as City I. Figure 16 contrasts the Recommended Concept with the BAU

004a. U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, [various] pp. Lovett, G. et al., 2009: Effects of air pollution on ecosystems and biological diversity in the eastern United States. Annals of the New York Academy of Sciences, 1162 (1), 99–135.

[6] Fann, N., et al., 2016: Ch. 3: Air quality impacts. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment., U.S. Global Change Research Program, Washington, DC, 69–98.

[7] Gamble, J., et al., 2016: Ch. 9: Populations of concern. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment., U.S. Global Change Research Program, Washington, DC, 247–286.

[8] Lovett, G. et al., 2009: Effects of air pollution on ecosystems and biological diversity in the eastern United States. Annals of the New York Academy of Sciences, 1162 (1), 99–135.

[9] Schnell, J. and Prather, M., 2017: Co-occurrence of extremes in surface ozone, particulate matter, and temperature over eastern North America. Proceedings of the National Academy of Sciences of the United States of America, 114 (11), 2854–2859.

[10] Dolwick, P., et al., 2018: Air Quality. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D., et al. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 512–538.

Scenario; it shows the difference in emissions of ozone pre-cursors —in kilograms (panel a) and as a % difference (panel b). The results are negative for NO_x (both from tailpipes and electricity generation) and for CO from tailpipes; however, emissions of NMHCs are higher under the Recommended Concept, by 0.9%. Note that emissions of NO_x from electricity generation amount to only 191 grams and 197 grams under the Recommended Concept and the BAU Scenario, respectively (hence, their apparent absence from panel a). All else being equal, ozone-related mortality and morbidity health effects in Edmonton with climate change are expected to be less under the Recommended Concept than the BAU Scenario.

Figure 15: Normalized emissions of ozone pre-cursors under Evaluation, BAU and BAP Scenarios

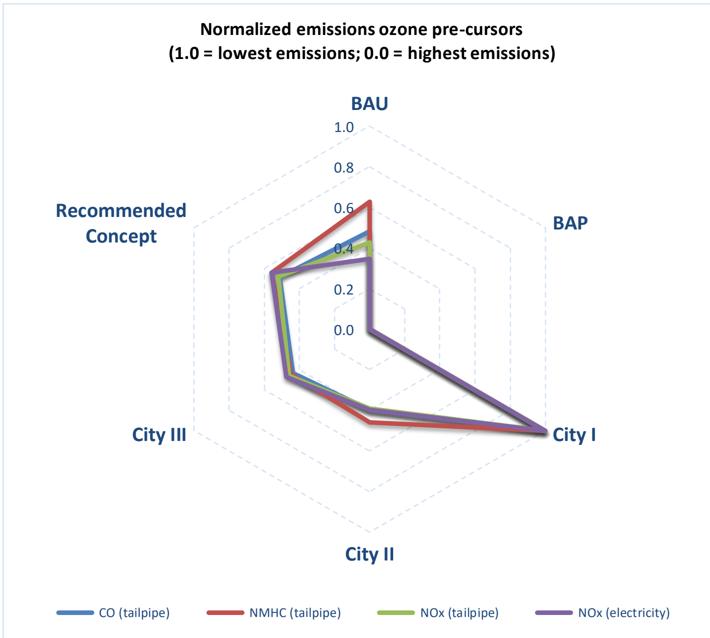
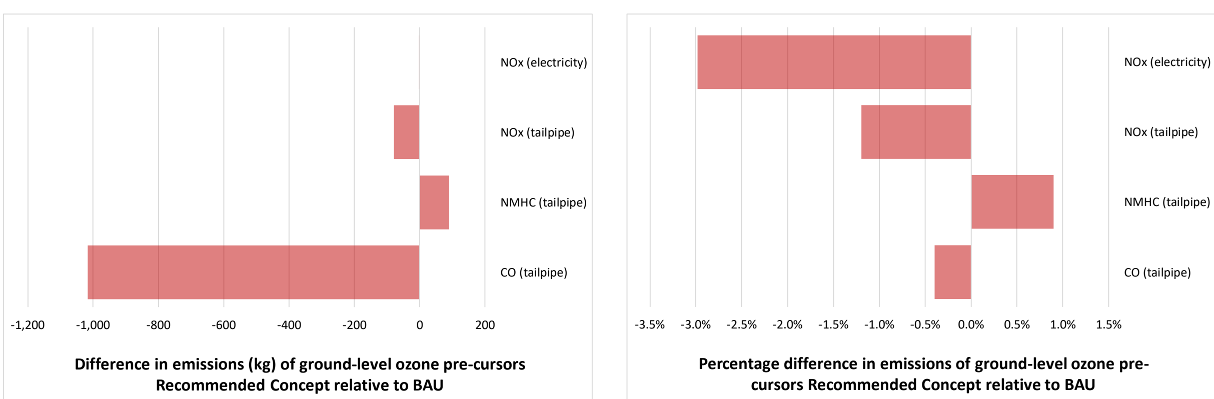


Figure 16: Differences in transport-related emissions of ozone pre-cursors under the Draft Recommended Land-use Concept relative to BAU Scenario

(a) (b)



4 Summary of Findings

4.1 Evaluation Scenarios

Results from the assessment of the relative climate change costs for the Evaluation Scenarios relative to the BAU Scenario are summarized in Table 1.

Table 1: Summary of climate change costs relative to the BAU scenario for select assets and service and impacts in 2065 (% difference)

Asset / Service Area	City I (Central)	City II (Node)	City III (Corridor)
Residential buildings	-13.5% (**)	-6.1% (*)	-18.2% (***)
Non-residential buildings	-10.8% (**)	-3.9% (*)	-11.4% (***)
Space heating and cooling	-87.9% (**)	-88.1% (***)	-86.6% (*)
Road transport infrastructure	-3.5% (***)	-1.6% (*)	-2.5% (**)
Road transport services	-11.6% (***)	-1.8% (*)	-3.9% (**)
Managed natural sites ^	0.20% (**)	0.18% (***)	0.21% (*)
Ecosystem services ^	3.97% (**)	3.76% (***)	3.98% (*)
Air quality and health	***	*	**

Note: *** = best performing Evaluation Scenario for indicator; * = worst performing Evaluation Scenario for indicator.
^ see caveat in main text: more open / green space (as per City II) increases units exposed to climate hazards and thus costs, but these costs do not account for the multiple benefits provided by such sites. Care should therefore be exercised when interpreting City II as the best performing scenario regarding managed natural sites and habitat.

4.2 Draft Recommended Land-use Concept

Results from the assessment of the relative climate change costs for the Recommended Concept relative to the BAU Scenario are summarized in Table 2; the impacts of climate change on air quality were assessed qualitatively and are not included in Table 2. Climate-related risks to the select assets and services considered in this study are reduced by roughly 8% (or $874 million, 2016 dollars) in 2065 under the Recommended Concept—through a combination of modifying the quantity, location and/or composition of the “stock-at-risk” to climate change. This represents the *annual* reduction in projected climate change costs *in* 2065 under the Recommended Concept compared to the BAU Scenario.

The Recommended Concept reduces climate change costs in 2065 by about 8%; however, that still leaves residual losses equivalent to 92% of projected costs under the BAU Scenario. Planning is but one mechanism that a city can use to adapt to the threats of climate change (recall Section 2.2). Further actions are necessary to reduce future climate-related risks faced by Edmonton to acceptable levels. Moreover, as a rule, urban densification does not necessarily reduce the physical risks of climate change. Indeed, if done without due diligence, it can increase the “stock-at-risk” to site-specific climate hazards, like flooding, by concentrating activity in high risk areas. While the Recommended Concept does reduce future climate change costs relative to BAU, mainstreaming detailed consideration of physical climate risks into location and design decisions moving forward will yield further—potentially significant—reductions in future impacts and costs, as well as generate climate mitigation co-benefits.

Table 2: Summary of climate change costs under Draft Recommended Land-use Concept relative to the BAU Scenario for select assets and service and impacts in 2065

Asset / Service Area	Economic costs ($ 2016 million)	% difference with BAU
Residential buildings	-347.0 (saving)	-7.3%
Non-residential buildings	-496.0 (saving)	-8.4%
Space heating and cooling	-29.4 (saving)	-85.8%
Road transport infrastructure	-3.2 (saving)	-7.5%
Road transport services	-0.5 (saving)	-5.4%
Managed natural sites ^	+0.5 (cost)	+0.2%
Ecosystem services ^	+1.7 (cost)	+4.1%
Net cost	**-874.0 (net saving)**	**-7.9%**

Note: ^ see caveat in main text: more open / green space increases units exposed to climate hazards and thus costs, but these costs do not account for the multiple benefits provided by such sites. Care should therefore be exercised when interpreting the additional costs of managed natural sites and habitat under the Draft Recommended Land-use Concept. Allow for rounding errors in totals.

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