A GREEN AND HEALTHY RECOVERY: HOW DIFFERENT GREEN ECONOMIC RECOVERY INVESTMENTS COMPARE FOR ADVANCING HUMAN HEALTH IN CANADA

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Smart Prosperity Institute

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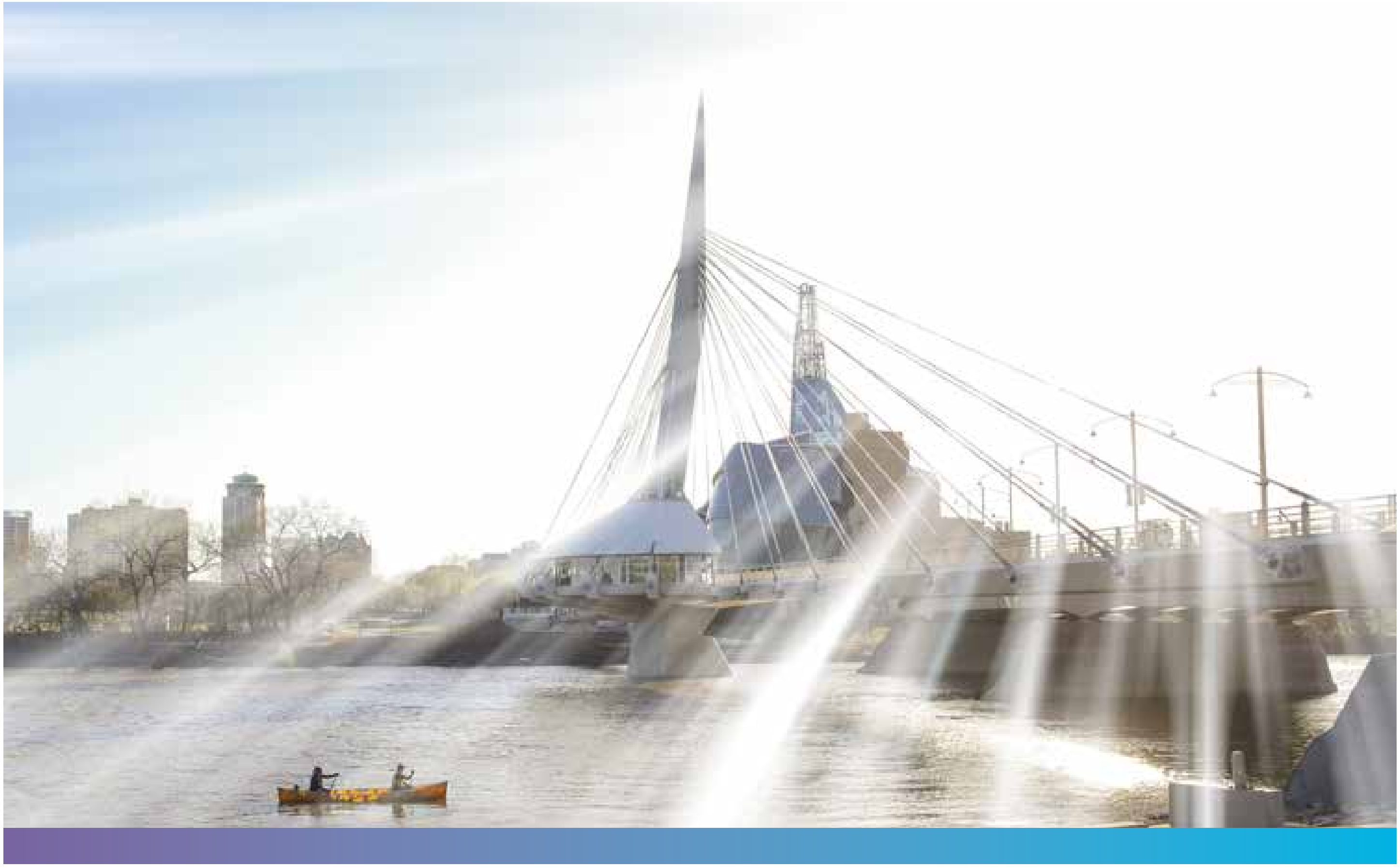
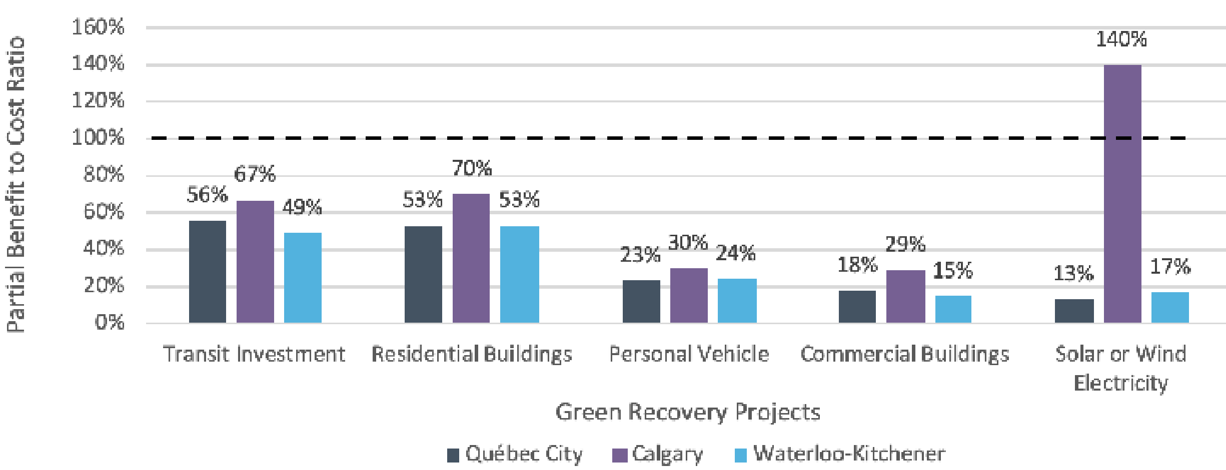


EXECUTIVE SUMMARY

In an economic downturn driven by the COVID-19 health crisis, recovery investments that support growth while also improving human health, and environmental outcomes are essential for fostering long-term resilience in line with the objective of building back better. This report analyses the comparative environmental and health benefits offered by five green recovery projects - energy efficiency retrofits for residential buildings, energy efficiency retrofits for commercial buildings, installing solar or wind generation capacity, getting zero-emissions public transit vehicles on the road, and getting zero-emissions personal

Figure 1: Partial benefit-to-cost[1] ratio for environmental and health benefits from green recovery projects, relative to $100 million investment



vehicles on the road – in three Canadian cities: Calgary, Québec City, and Waterloo-Kitchener. This comparative assessment focusses on some of the benefits, i.e. the health benefits arising from improvements in air quality from reductions in two pollutants (particulate matter 2.5 ($PM_{2.5}$), and nitrogen dioxide (NO_2), and the value gained from reducing greenhouse gas (GHG) emissions, from spending a $100 million sum on five green recovery projects in each city.

The results of the partial cost-benefit screening-level analysis are as follows:

- **Residential buildings and transit investments deliver the highest level of average annualized benefits across all three regions.** The largest benefit is from GHG reductions, but also high particulate matter reductions, leading to reduced health outcomes
- **Renewable electricity projects in Calgary offer the highest overall level of benefit of any project.** These benefits are 8 to 10 times higher than similar investments in Waterloo-Kitchener and Québec City, where electricity is largely decarbonized. This result is a reflection of the grid intensity of electricity in Alberta. Given the ongoing decarbonization in the electricity sector in Alberta, this current high benefit is expected to fall over time.
- **In all three regions, energy efficiency retrofits for commercial buildings delivered the lowest benefits**. This is a function of the high efficiency of commercial boilers and the relatively lower air pollutant emissions intensity per unit of energy, and the low level of emission reductions that can be attained through deep decarbonisation retrofits[2].

The table below provides a summary of results by project type, comparing the total reductions of GHGs, $PM_{2.5}$, and NO_2 across each project and region.

Table 1: Results by Project Type (for $100 million in spending by project)

Type of Project	Location	Total Emission Reductions (tonnes)			Total Value (NPV @ 3%: $M 2020)				Annual Value ($M)
		CO_2e	$PM_{2.5}$	NO_2	CO_2e	$PM_{2.5}$	NO_2	Total	
Residential Buildings	Calgary	1,020,000	768	559	$52.60	$4.53	$0.08	$57.20	$2.92
	Waterloo-Kitchener	775,000	1,260	501	$40.10	$3.05	$0.13	$43.20	$2.20
	Québec City	643,000	2,980	607	$33.20	$9.79	$0.24	$43.30	$2.21
Commercial Buildings	Calgary	446,000	238	1,130	$23.10	$1.40	$0.17	$24.60	$1.26
	Waterloo-Kitchener	222,000	121	1,250	$11.50	$0.29	$0.33	$12.10	$0.62
	Québec City	269,000	134	1,310	$13.90	$0.44	$0.53	$14.80	$0.76
Solar or Wind Electricity	Calgary	2,070,000	82	3,110	$114.0	$0.58	$0.56	$115.0	$7.73
	Waterloo-Kitchener	258,000	14	541	$14.10	$0.04	$0.17	$14.30	$0.96
	Québec City	187,000	24	1,330	$10.20	$0.09	$0.64	$11.00	$0.74
Transit Investment	Calgary	635,000	3,620	2,910	$32.80	$21.40	$0.44	$54.60	$2.79
	Waterloo-Kitchener	669,000	2,130	2,790	$34.60	$5.15	$0.73	$40.40	$2.06
	Québec City	742,000	2,100	1,370	$38.30	$6.92	$1.10	$46.30	$2.36
Personal Vehicle	Calgary	333,000	605	487	$18.80	$4.73	$0.10	$23.60	$1.98
	Waterloo-Kitchener	322,000	310	405	$18.20	$0.99	$0.14	$19.30	$1.62
	Québec City	311,000	284	370	$17.60	$1.24	$0.20	$19.00	$1.59

This analysis identifies key findings across each region:

Calgary

- **Overall benefits from investing in solar and wind energy projects are 2 to 5 times larger than other green recovery investments**. Investing in transit decarbonization and retrofitting residential buildings also offer significant environmental and health benefits for Calgary.

- Investments in public transit offer the largest health benefits through reduced consumption of diesel fuel.

Québec City

- **Getting zero-emissions public transit vehicles on the road and improving the energy efficiency of residential buildings** are the two project categories that offer the largest overall environmental and health benefits to Québec City residents.

- Residential buildings offer larger health benefits, whereas transit investment will bring forth greater environmental benefits through greenhouse gas emission reductions.

Kitchener-Waterloo

- **Getting zero-emissions public transit vehicles on the road and improving the energy efficiency of residential buildings** also offer the highest overall environmental and health benefits to the Waterloo-Kitchener region, similar to the analysis in Québec City.

- In contrast with Québec City, transit investments bring about greater health benefits, whereas retrofitting residential buildings results in larger environmental benefits.

Informed by these findings, this report set out three recommendations to assist policymakers credibly integrate health and environmental considerations into spending decisions in a green recovery context.

1. Cost-Benefit analysis of green recovery investments should consider gains from health benefits in addition to environmental benefits, even if only a subset of environmental and health benefits are considered.

2. Recovery spending decisions should be place-specific and should consider health and environmental outcomes for local communities.

3. Recovery projects that offer the highest benefits in terms of health and environmental impact should be prioritized over others.

This report demonstrates that there is a strong economic case for investing in green recovery projects, given the substantial health and environmental gains they bring about. Moreover, it shows that local context matters and that policymakers must take into account their regional context when deciding on recovery spending.

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LIST OF ABBREVIATIONS

AQBAT	Air Quality Benefits Assessment Tool
CACs	Criteria, or Common, Air Contaminants
CAPE	Canadian Association of Physicians for the Environment
CGE	Computable General Equilibrium
CMA	Census Metropolitan Area
COPD	Chronic Obstructive Pulmonary Disease
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IMF	International Monetary Fund
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
NPV	Net Present Value
OECD	Organization for Economic Cooperation and Development
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter (2.5)
Solar PV	Solar Photovoltaic
ZEVs	Zero-Emission Vehicles

INTRODUCTION

The COVID-19 pandemic has served as a strong reminder of the interconnectedness of Canada's society, economy and communities, with health and the environment. The clear systemic implications of combatting a pandemic have caused many leaders, including former bank of Canada governor Mark Carney, to draw links towards the similar systemic threats posed by a changing climate[3]. As Canada emerges from the pandemic, these linkages have been further emphasized by discussions of the importance of supporting a green economic recovery (see Box 1) from COVID-19. This green recovery offers an opportunity to advance multiple outcomes, including supporting economic growth, climate action, and enhancing Canada's overall resilience to future crises.

One significant opportunity for capturing benefits in a green recovery lies in investing in projects that could improve human health and environmental outcomes. The potential for improving health outcomes through the types of projects advanced in a green recovery is well-documented. A report on the potential for a green and healthy recovery by the Canadian Association of Physicians for the Environment (CAPE) identified that, due to improved air quality from meeting emission reduction targets and climate action, Canada has the potential to cumulatively avoid 112,081 deaths between 2030 and 2050[4]. This potential is substantial, and an ambitious green recovery that invests in projects aligned with a net-zero emissions future can help realize some of these benefits within the coming decade.

One significant opportunity for capturing beneffits in a green recovery lies in investing in projects that could improve human health and environmental outcomes.

While national assessments or forecasts, like the CAPE report mentioned above, are useful for evaluating the overall potential to advance health, they offer limited insight into how a given project may improve the environment or impact the health of local communities in a given region. Conducting even a cursory assessment of the benefits that accrue in individual communities requires evaluating how deployment of a given project will intersect with factors such as the emissions intensity of energy used and displaced, regional air quality, and the impacts of a project on local communities. Importantly, these factors mean that different projects are likely to offer varying levels of benefits to different cities. Certain cities with higher levels of industrial activity may have higher concentrations of certain air pollutants such as $PM_{2.5}$ [5] making projects whose deployment is tied to reductions in those pollutants potentially more attractive from a human health perspective.

This report addresses this challenge by undertaking a comparative assessment of the health benefits of five prominent green recovery projects in three regions across Canada: Calgary, Québec City, and Waterloo-Kitchener. This comparative assessment focusses on evaluating some of the benefits, i.e. the health benefits arising from improvements in air quality, and the value gained from reducing GHG emissions, from spending a $100 million sum each on five green recovery projects in each city. Such a screening-level assessment will allow policymakers to better identify how different projects offer different health benefits depending on where they are deployed. This diversity in impacts is significant because project spending in a green recovery is likely to be targeted towards certain types of green recovery projects. Understanding the health benefits offered by different projects (examples of projects could be improving the energy efficiency of multi-unit residential buildings, and electrifying public transit vehicles) can allow for a comparative assessment around which projects may offer the largest health and environmental benefits in different communities, thereby identifying key differences that can inform spending decisions.

The objective of this screening analysis is not to prescriptively outline what the health impacts of a green recovery would be nationally, but to offer insights to policymakers about how various green recovery measures could influence health and environmental outcomes in each city differently. This report's analysis also demonstrates the importance of adapting investment decision-making to the local context. Moreover, this analysis provides the starting point for a discussion around the need for better targeting spending in a green recovery to communities who stand to benefit the most from particular measures – a critical step in moving towards designing policies that advance projects that best suit the needs of community members. Finally, it offers an important lens to move discussions of potential health benefits from assessments of technical potential into discussions of realizing this potential in practice.

Box 1: What is a green recovery?

An economic recovery is defined as a return to economic growth, typically measured as a minimum of two consecutive quarters (a six-month period) of economic growth following a recessionary period. Discussions around a green economic recovery arose prominently in the months following the initial lockdowns from COVID-19. There are a few ways to define a green economic recovery. The "greenness" of a given economic recovery can be defined as the extent to which individual investments made in an economic recovery are tied to improvements in environmental performance through directly reducing greenhouse gas emissions, improving the efficiency of resource use or investing in nature or natural solutions (Vivid Economics, 2020).

This report uses the definition that a green economic recovery, referred to as a green recovery, is an economic recovery composed primarily of investments in individual projects that offer meaningful improvements in environmental performance (reductions in greenhouse gas emissions, waste streams or pollution streams, increased levels of natural conservation and/or restoration, or improvements in the resource efficiency) relative to available alternatives. This definition does not exclude the need for an economic recovery to support economic growth through job creation and increased investment, nor does it exclude the imperative to invest in solutions that support greater equity and inclusion in the Canadian economy (Smart Prosperity Institute, 2020).

Overview of Report

This report evaluates a number of the health and environmental benefits from deploying green recovery projects in Canada. In doing so, two overarching questions are sought to be answered:

- How do various green recovery projects compare against each other in terms of their air pollution mitigation potential, in specific Canadian cities?
- Which green recovery projects offer the most value to select Canadian cities in terms of avoided adverse health costs and improved environmental outcomes?

As a first step towards answering these questions, five green recovery projects that have been advanced in at least 50% of the green recovery reports[6] examined, and that meet the screening criteria outlined in Appendix 1, are identified. An overview of the health benefits, and avoided adverse impacts associated with deployment of these projects follows.

This report features a screening-level comparative assessment of the value of the health and environmental benefits arising from spending a $100 million sum on each of the five types of green recovery projects. Health benefits arising from reductions in air pollution form the primary focus of this report, since improvements in air quality offer direct and local environmental benefits to the communities where projects are constructed. The analysis is centered around how reductions in two pollutants – particulate matter 2.5 ($PM_{2.5}$) and nitrogen dioxide (NO_2) – influence health outcomes in three cities: Calgary, Québec City, and Waterloo-Kitchener. These two pollutants were selected based on the established scientific evidence linking exposure to negative health impacts[7], and because of their inclusion within the Navius g-Tech model, from which projections were used that formed the baseline scenarios against which greenhouse gas and air pollution emissions impacts were evaluated.[8] These three cities were selected based on an analysis of local air quality, population, economic make-up, and a desire to reflect inter-regional diversity, outlined in Appendix 3. The quantitative analysis, which illustrates what spending the same $100 million sum on different projects in different regions would comparatively yield in terms of environmental and health benefits, is followed by a set of recommendations on how investments in a green recovery could be appropriately targeted to advance positive outcomes for both the environment and human health.

This report features a screening-level comparative assessment of the value of the health and environmental benefits arising from spending a $100 million sum on each of the five types of green recovery projects.

PROMINENT GREEN RECOVERY PROJECTS BEING ADVANCED

The first step in this analysis was to identify which projects[9] fit under the banner of advancing a green recovery. Identifying which types of projects to evaluate was the subject of a literature review that examined prominent green recovery reports from leading environmental organizations from both within and outside Canada. The 13 reports examined in this literature review, which can be seen in Appendix 1, include prominent national reports and a few international examples that were frequently referenced in Canadian economic recovery discussions. A set of screening criteria, also laid out in Appendix 1, was applied to the initial list of green recovery projects identified from these reports, to ensure that they were broadly supported i.e. appeared in more than 50% of the reports reviewed, specific enough to classify as distinct projects, and offered measurable impacts. Applying this set of screening criteria to the analysis of projects identified the following projects, referred to as prominent green recovery projects, seen in Table 2 below.

The seven projects listed in table 2 can be classified into five project categories:

- Energy efficiency retrofits for residential buildings (includes both residential building retrofits and housing retrofits),
- Energy efficiency retrofits for commercial buildings,
- Installing solar or wind generation capacity,
- Zero-emissions public transit vehicles, and
- Zero-emissions personal vehicles.

Table 2 : List of prominent green recovery projects advanced in Canada

#	Green Recovery Project	Number of reports recommendation appeared in	% of reports recommendation appeared in
1	Residential building retrofits – energy efficiency	11	85%
	Housing retrofits – energy efficiency	7	54%
2	Commercial building retrofits – energy efficiency	12	92%
3	Installing solar electricity generation	10	77%
	Installing wind electricity generation	9	69%
4	Zero emissions vehicles – public transit	7	54%
5	Zero emissions vehicles – personal vehicles	11	85%

Each of these five project areas are briefly described below:

Energy efficiency retrofits for residential buildings: This project type includes housing retrofits for residential homes and multi-unit residential buildings. Within the residential housing sector, deep retrofits involve significant retrofits to the building shell (insulation improvements for the thermal envelope to reduce leakage of heat), and replacements of heating, cooling and hot water systems. Retrofits for homes that have been outlined in green recovery reports include thermal retrofits to enhance insulation, and often include the installation of ground-source or air-source heat pumps to help transition homes away from a reliance on natural gas for heating[10]. Deep energy efficiency retrofits of multi-unit residential buildings go beyond improvements to the existing building envelope and call for significant reconfiguration, replacements or rearrangements of the interior, windows, and heating and ventilation systems. It should be noted that these retrofits can prove disruptive to occupants and are best conducted during periods of unit inoccupancy or tenant turnover[11].

Energy efficiency retrofits for commercial buildings: This measure focuses on expanding deep retrofits to more commercial and public buildings with a specific emphasis on schools, social housing, and hospitals. Although no single, overarching definition of deep retrofits exists[12], deep retrofits generally involve extensive renovations to improve the energy efficiency, and resilience of a building with an objective of achieving at least a 50% reduction in on-site energy usage compared to pre-retrofit[13]. Measures within deep retrofits may include significant reconfigurations of the interior, replacing the roof, adding or rearranging windows to increase daylight or replacing the existing heating, ventilation and air conditioning systems with renewable technologies[14]. While retrofits can also be targeted towards improving resilience to climate impacts, green recovery reports focused primarily on advancing retrofits to improve energy efficiency, decrease reliance on fossil fuels, lower energy costs, and reduce maintenance requirements[15].

Installing solar or wind power generation capacity: This measure involves installing greater levels of solar photovoltaic (PV) panels onto electricity grids across Canada, and increased use of wind generated electricity on electrical grids across Canada by increasing the number of power-generating wind turbines. Deployment of solar PV can be grid-scale or residential-scale and is not preferential to a particular commercially available solar PV panel technology. Overall expanded deployment of this renewable source of electricity will aid in the transition away from emitting sources of electricity such as coal and natural gas[16].

Zero-emissions public transit vehicles: This measure includes investments in technology and infrastructure, alongside accessibility improvements, to ensure zero-emission public transit vehicles are more widely used. Similar to personal vehicles, battery-electric and hydrogen vehicles are the two dominant technology pathways advanced in green recovery reports. Both are referred to as zero-emissions public transit vehicles in this report.

Zero-emissions personal vehicles: The majority of green recovery reports highlight pathways to encouraging greater and widespread use of zero-emissions vehicles. Deployment of zero-emission personal vehicles refers to the emissions profile of the end-use technology and does not necessarily prescribe a specific technology pathway for reaching that target. However, while the name itself does not imply a specific end-use technology, almost all reports identify that battery-electric vehicles are the technology that should be supported. A few reports also mention hydrogen fuel cell vehicles as a zero-emissions vehicle option. This report will refer to both technologies as zero-emissions vehicles.

The project categories listed in Table 1, and described above, form the basis for the analysis in this report. A detailed write-up of how reports propose these measures be advanced by policies and spending is included in Appendix 2. The next section of this report briefly reviews health literature to identify the health benefits associated with the deployment of these projects.

HEALTH IMPACTS AND PROMINENT GREEN RECOVERY PROJECTS

The deployment of the five green recovery project categories outlined above will reduce the combustion of fossil fuels. Buildings, energy and transportation technologies that combust fossil fuels for operations also produce a number of air pollutants known as criteria air contaminants, or common air contaminants (CACs). CACs is a collective term used to refer to a set of air pollutants, mainly emitted through fossil fuel combustion, that are known to cause adverse health impacts[17]. Examples of CACs include particulate matter, nitrogen dioxide, sulphur dioxide, ozone, and carbon monoxide. In this report, the impact of the five green recovery projects on two CACs – particulate matter 2.5 and nitrogen dioxide – are analysed.

- **Particulate matter ($PM_{2.5}$)**: Also known as "fine PM"[18], $PM_{2.5}$ particles are approximately 2.5 micrometers or smaller and are inhalable[19]. Particulate matter, also called particle pollution, is composed of solid fragments and liquid droplets of varying sizes found in the air[20]. Some particles are visible like dirt, soot, smoke, and dust, and others are too small to be seen with the naked eye[21].

- **Nitrogen dioxide (NO_2)**: When fossil fuel combustion occurs, nitrogen is released into the atmosphere where it combines with oxygen to produce NO_2[22]. Nitrogen dioxide is a brown gas with a hazardous odour[23].

These two pollutants have been selected because emissions of these pollutants are included in the scenario projections model this report uses to identify emissions changes resulting from different projects[24]. These forecasts are developed from scenarios modelled by the g-Tech, a North American environment-economy model operated by Navius Inc.[25]. An overview of the methodology used in this report to undertake this modelling can be found in the methodology section later in the report.

Potential health benefits from reductions in air pollutants

The deployment of green recovery projects offers direct health benefits to individuals. These benefits are traditionally conceptualized within climate policy discussions as health 'co-benefits'. Health co-benefits are the ancillary positive health impacts that result from policies, projects or programs aimed at reducing greenhouse gas emissions, supporting greater environmental conservation or supporting cleaner economic growth.

Reduction in concentrations of $PM_{2.5}$ and NO_2 is associated with a wide range of public health and air quality benefits. Potential health benefits associated with reduced exposure to $PM_{2.5}$ include avoidance of premature death, increased life expectancy, avoided cardiovascular complications such as stroke, non-fatal heart attacks, acute myocardial infarctions, ischemic heart disease mortality or stroke mortality, and avoided respiratory conditions including respiratory illnesses, chronic obstructive pulmonary disease (COPD), asthma-related emergency room visits, and avoided COPD mortality[26]. These benefits can also be realized for children; studies have identified associations between healthier lung growth and a decline in $PM_{2.5}$ and NO_2 concentrations[27]. More specifically, the health co-benefits from reductions in $PM_{2.5}$ and NO_2 through green recovery projects centered around buildings, energy, and transportation are discussed below.

Energy efficiency retrofits for residential and commercial buildings

Investing in energy efficient and retrofit buildings offers key health benefits following a reduction in $PM_{2.5}$ and NO_2 emissions. One study modelled the health benefits of green buildings and found positive outcomes to include avoided premature deaths, hospital admissions, respiratory symptoms, asthma exacerbations, and lost days at school and work[28]. Another study found associations between green buildings in low-income housing and fewer symptoms for sick building syndrome in adults, as well as a lower risk of asthma symptoms, asthma attacks, hospital visits and asthma-related school absences[29]. There are additional benefits children acquire from retrofitted, greener residential buildings – a study from New Zealand found children to have a lower likelihood of being underweight[30]. Major sources of these pollutants in residential structures are stoves, furnaces and home heating[31].

Installing solar or wind generation capacity

Power plants generating electricity, especially those that rely on coal combustion, are prominent sources of $PM_{2.5}$ and NO_2[32]. Therefore, renewable energy projects that displace electricity generated from coal-fired generation have the potential to generate health co-benefits. Modelling suggests that these benefits are associated with avoided premature deaths[33]. Modelling health benefits from a transition to zero-emission renewable projects from emitting coal-fired plants in Northern China revealed that a decrease in NO_x and SO_2 resulted in 2.3 fewer premature deaths, on average, per 1.6 million people per year[34]. This same study also modelled benefits such as fewer hospitalizations for cardiovascular and respiratory illnesses, decreases in chronic bronchitis cases per year, and improved cardio-pulmonary conditions in affected populations from NO_2 reduction[35].

Zero-emissions transit and personal vehicles

Transportation that uses fossil fuel combustion emits PM and NO_2. $PM_{2.5}$ and NO2 emissions can arise from motor vehicle exhaust, diesel engine use, and gasoline combustion[36]. Pollutant concentrations tend to be higher in highly trafficked areas or near-road sites[37]. Accordingly, car and fleet electrification are good interventions for reducing tailpipe $PM_{2.5}$ and NO_2 emissions. Modelling projections indicate decreases in premature mortality subsequent to the adoption of electric vehicles[38]. Health benefits are however dependent on regional context, adoption rates, and the sources of power generation used to charge electric vehicles[39]. NO_2 reduction from electric vehicles could increase life expectancy and decrease mortality[40]. Similarly, modelling conducted in 2014, for the United States light-duty transportation sector demonstrates that 3,710-6,350 deaths per year can be avoided due to $PM_{2.5}$ concentration changes with a 100% instantaneous replacement of on-road vehicles using fossil fuels to hydrogen-powered vehicles[41].

Adverse health impacts that can be avoided through green recovery projects

The health ramifications of human exposure to particulate matter and nitrogen dioxide have been clearly identified in research. These pollutants can have adverse impacts on mortality, mental health, noncommunicable diseases, and health systems including: cardiovascular, respiratory, neurological, gastrointestinal, and reproductive. However, research evidence suggests that the strongest associations are between $PM_{2.5}$ and NO_2 exposure and cardiovascular, respiratory, and mortality outcomes, with $PM_{2.5}$ having a causal relationship with cardiovascular effects and mortality, and NO_2 having a causal relationship with respiratory effects in the short term [42].

There is a plethora of cardiovascular impacts that arise from exposure to $PM_{2.5}$ and NO_2. The United States' Environmental Protection Agency (EPA) found $PM_{2.5}$ to be causative of cardiovascular effects after short-term and long-term exposure[43]. According to Health Canada, short-term exposure (24-h) to $PM_{2.5}$ is causally associated with cardiac emergency room visits and cardiac hospital admissions[44]. Short-term exposure to $PM_{2.5}$ is also associated with ischemic heart disease, acute myocardial infarction, cardiopulmonary morbidity, and heart failure, all of which may play a role in increased hospitalizations[45]. Long-term exposure to $PM_{2.5}$ is related to hypertension, ischemic heart disease, and atherosclerosis[46]. NO_2 exposure is positively associated with cardiovascular diseases, such as coronary heart disease, hypertension, and stroke[47]. Short-term exposure to NO_2 has been found to be associated with risk of heart failure, hypertension and emergency hospitalization whereas longer exposures could be related to ischemic heart disease or stroke[48].

Respiratory effects from $PM_{2.5}$ and NO_2 exposure vary in manifestation and severity. High concentrations of $PM_{2.5}$ are associated with asthma hospitalizations[49]. Respiratory symptom severity in children is associated with traffic-related increases in $PM_{2.5}$ concentration[50]. Lung functionality may worsen in children even when exposed to low concentrations of $PM_{2.5}$[51]. Health Canada determined acute exposure (24-h) to $PM_{2.5}$ to be causal of acute respiratory symptom days, asthma symptom days, child acute bronchitis episodes, respiratory emergency room visits, respiratory hospital admissions, and restricted activity days[52]. The EPA found NO_2 to be causative of respiratory effects[53]. Short-term and long-term exposures can lead to outcomes like asthma, wheezing, persistent cough and phlegm, chest tightness, allergic rhinitis, emphysema, shortness of breath, and more severe consequences like pneumonia, chronic obstructive pulmonary disorder, chronic bronchitis, cancers, and mortality[54]. Exposure has also been positively associated with reduced lung function from stunt lung growth in children[55].

Mortality is a health consequence associated with $PM_{2.5}$ and NO_2 exposure. Evidence suggests a relationship between short- and long-term exposure to $PM_{2.5}$ and mortality, including associations with increased overall respiratory death, increases in daily total mortality, and mortality risk for those with chronic morbidities[56]. However, mortality is dependent on length of exposure to $PM_{2.5}$. The relationship between NO_2 and mortality is still debated in literature. While some research has found a positive association between cardiovascular mortality and NO_2 exposure, there is evidence that suggests that this relationship is confounded by $PM_{2.5}$ exposure[57]. Health Canada has determined that NO_2 is likely causal of mortality due to acute exposure (24-h)[58].

Box 2: A note on interpreting health impacts

It is important to note that when discussing the health benefits emerging from particular projects, any impacts identified are based in specific examples or case studies. Health co-benefits, and health impacts more broadly, can vary in scope and scale, depending on whether they include both direct and indirect effects, the time scale being used to consider health impacts, and which biological systems are being examined. It is difficult to account for health impacts from projects in the abstract given the prominent role that contextual factors play in influencing health outcomes. Scale is also relevant in these discussions; deployment of a single electric public transit vehicle is unlikely to have a meaningful impact on regional air quality.

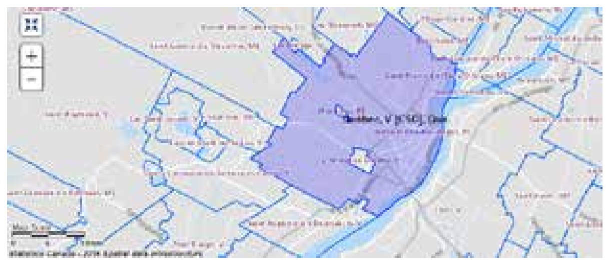
Exposure to particulate matter and nitogen dioxide can have adverse impacts on mortality, mental health, noncommunicable diseases and health systems, including; cardiovascular, neurological, gastointestinal and reproductive.

HEALTH AND ENVIRONMENTAL IMPACTS OF GREEN RECOVERY PROJECTS

As detailed above, the project categories discussed in green recovery reports offers health benefits to communities through reductions in CACs emissions, and consequent improvements in air quality. While many of these benefits are common across projects, realized health benefits will differ in practice based on regional, temporal, and geographic factors. Therefore, a screening-level analysis of health impacts across different projects in different cities to identify how building certain projects might offer significant health benefits to certain Canadian cities becomes important.

To this end, this report looks into three Canadian cities – Calgary, Québec City, and Waterloo-Kitchener – and assesses the comparative value that will accrue from air quality improvements from implementing the five prominently discussed green recovery projects in these cities. As detailed in Appendix 3, these three cities were selected based on an analysis of local air quality, population, economic make-up and a desire to reflect inter-regional diversity. Figure 2 below illustrates the boundaries within which these analyses were conducted.

Figure 2 : The three regions assessed

Geographic Area	2020 Population	Area	Map
Waterloo-Kitchener, Regional Municipality Census Division, Ontario	535,154	1,369 km^2	
Calgary, City Division No. 6, Census division, Alberta	1,239,220	826 km^2	
Québec, Ville Census division, Québec	531,902	453 km^2	

The screening analysis looks into whether certain project categories offer higher overall benefits than others in these cities. This comparative analysis is not meant to prescriptively recommend precisely whether spending on a certain project should be directed towards only one city. It is meant to be illustrative of variance in outcomes between both projects and regions and offer insight into how health benefits arising from green recovery projects could be considered within a recovery through a community-centered lens. It also bears mentioning that while any analysis of a single factor, such as air quality improvements resulting from reductions in two pollutants, on human health will not offer the in-depth insight needed to completely understand the full range of health impacts experienced by a community from a project, it can still support the integration of greater health considerations into decision-making. This, in turn, can inform where spending might offer higher benefits to community members.

Methodology

To calculate the value of emission reduction benefits of prominent green recovery projects, this report undertakes a three-step analysis:

Step 1: Estimating emission reductions from green recovery projects

Emission reductions from green recovery projects are calculated for each city based on a $100 million expenditure for each project. For each investment, total benefits are estimated based on the assumed capital life of the green investments. Residential, commercial, and transit capital investments have a 30-year life; the personal vehicle investments are 15 years; and solar and wind investments have a 20-year life. In order to calculate the reductions in GHGs, $PM_{2.5}$ and NO_2 resulting from investments, this report uses a set of scenarios developed and modelled by the Navius Research g-Tech model (see Box 3)[59]. The g-Tech model runs different scenarios in which Canada achieves national GHG emission reductions equal to the latest national target, which is 40 to 45% below 2005 levels in 2030, and then to net-zero GHG emissions by 2050.

The scenario projections used in this report to estimate emissions reductions against a baseline, modelled by the g-Tech, are based on a standard Navius reference case that assumes broad-based and ongoing deployment of low emitting, and energy efficient capital with the goal of reaching net-zero GHG emissions by 2050. This reference case forms the baseline within which changes in emissions are measured for this project. Specific policies incorporated into the reference case include: a broad-based carbon price that rises to $50/tonne by 2022, then falls

The model... represents what deploying $100 million in a green recovery might incur in a world where Canada's current cliamte targets are met through other investments" OR "The economic values attached to health benefits from reduced air pollution includes poetntial social, eocnomic and public welfare consequences such as medical costs, reduced workplace productivity, pain and suffering and other effects of increased health risks.

in real terms by 2030; national vehicle efficiency standards for light- and heavy-duty vehicles; equipment efficiency standards; and provincial biofuel mandates. This reference case is somewhat similar to the decarbonization scenario modelled by Environment and Climate Change Canada[60]. While there is some uncertainty as to which specific green investments or technologies are considered within the model itself, the wide range of technology solutions that are included in the model minimizes the chance that the wide range of green technologies discussed in this report are not reflected in estimates of emissions reductions.

From this baseline, the incremental change in emissions intensity is calculated by estimating the impact of deploying additional capital of $100 million dollars into each category of green recovery project. In effect, the model captures the incremental emissions improvement associated with additional capital investment over and above a net-zero emissions by 2050 pathway to represent what deploying $100 million in a green recovery might incur in a world where Canada's current climate targets are met through other investments.

Step 2: Estimating changes in air quality resulting from emissions reductions

Once changes in emissions of GHGs, $PM_{2.5}$, and NO_2 are estimated, the next step is evaluating changes in air quality emerging from the adoption of each project in each region. This analysis employed a reduced-form tool (see Appendix 6 for details) to evaluate changes in air quality specific to the Census Metropolitan Areas (CMAs) under consideration. None of the study regions has an existing emissions inventory for $PM_{2.5}$ and NO_2, and this analysis therefore used a range of data sources to determine the emissions profile of each region. Emissions inventories for NO_2 and $PM_{2.5}$ for each of the three regions were developed from the CACs inventory produced for each province by Environment and Climate Change Canada[61]. The provincial CACs inventories breaks out emissions into 157 different sectors. An urban/rural relevancy factor for each emissions sector was assigned, and then scaled the resulting urban emissions of NO_2 and $PM_{2.5}$ using the proportion of the region's population relative to the provincial population.

Table 3 presents NO_2 and $PM_{2.5}$ emissions for each region and province for the most recent emissions reporting year available (2017).

Table 3 : NO_2 and $PM_{2.5}$ Annual Emissions by Region and Province, 2017

Region	Annual Emissions	
	NO_2 (t)	$PM_{2.5}$ (t)
Calgary	**24,725**	**9,586**
Alberta	637,218	590,655
Waterloo-Kitchener	**7,788**	**3,380**
Ontario	299,778	270,453
Québec City	**9,467**	**4,224**
Québec	196,370	211,295

The percentage change that could be expected from each investment was then calculated, and this percent change figure was applied to each local pollutant concentration. A linear response between emissions and local air pollution was assumed, which provides an approximation for the two primary pollutants in this analysis[62]. The local pollution concentration is defined in this study as the regional concentration reported in Health Canada's Air Quality Benefits Assessment Tool (AQBAT) minus the background concentration (i.e., the portion of urban air pollution that is the result of air emissions generated outside of the region)[63].

Step 3: Calculating the value of environmental and health benefits

To calculate the potential screening-level air quality benefits emanating from the air quality changes brought on by emissions reductions from green recovery projects, this report used Health Canada's reduced-form Air Quality Benefits Assessment Tool (AQBAT) (see Box 3). To calculate air quality benefits, AQBAT allows for the construction of scenarios to compare how changes in air quality influence health outcomes. These scenarios, defined by the user, can factor in variables such as technologies deployed (e.g., age, efficiency, fuel choice) and end-use demand (e.g., weather, types of industry and commercial activities, size of homes, population), density of population and proximity to air pollution sources, and background concentration of air pollution.

Finally, the dollar value of the health benefits is calculated by taking into account both the social cost of carbon associated per tonne of emissions, and the value gained from changes in health outcomes from reduced air pollution. The social cost of carbon is valued at CDN $67 in 2020[64], climbing an annual rate of 1.7% to ultimately equal $79.60 in 2030. Health benefits are estimated using Health Canada's AQBAT. The valued health endpoints included in this analysis are highlighted in Table 4 below. The economic values attached to health benefits from reduced air pollution includes potential social, economic, and public welfare consequences such as medical costs, reduced workplace productivity, pain and suffering and other effects of increased health risks.[65] An important note is that the benefits represented in this analysis are done so using national figures, as both the health endpoint values used by the Health

Table 4 : Health endpoints valued in this analysis[66]

Pollutant	Valued Health Endpoints	
NO_2	Acute exposure mortality	
$PM_{2.5}$	Chronic exposure mortality	Cardiac emergency room visits
	Acute respiratory symptom days	Child acute bronchitis episodes
	Adult chronic bronchitis cases	Respiratory emergency room visits
	Asthma symptom days	Restricted activity days

Canada, and the social cost of carbon value used in this report, are not specific to any individual CMA included in this analysis. This allows for a common comparison of benefits across each community.

This report uses four indicators to represent the comparative value of green recovery projects in the three cities. These are:

- The quantity of emissions reduced over the life of each project type by region in metric tonnes (Mt);
- The net present value (NPV) of the stream of benefits;
- The annualized benefits to allow for comparison across projects with differing capital lives; and,
- A partial benefit cost ratio to compare the $100 million investment to the partially valued economic benefits expected from the green recovery investments.

Further details on each indicator including the formulas used and the financial assumptions made can be found in Appendix 4 to this report. Limitations of the analysis are described in Appendix 5.

Box 3: About the g-Tech and the Air Quality Benefits Assessment Tool (AQBAT)

g-Tech

Scenarios from the g-Tech model, developed by Navius Research, are used to estimate emissions changes that come from deploying projects within a decarbonizing baseline. The g-Tech is a computable general equilibrium (CGE) model that represents transactions between all sectors of the economy as measured by Statistics Canada national accounts. Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services, and the transactions that occur between households, firms, and government. As such, the model provides a forecast of how government policy affects many different economic indicators, including gross domestic product, investment, household income, and jobs. The model includes 95 sectors across all Canadian provinces, the territories, and the United States. The g-Tech accounts for all major energy supply markets, such as electricity, refined petroleum products, and natural gas. Importantly, the g-Tech accounts for technological change and is behaviourally realistic, allowing the model to explicitly account for how changes in technologies and behaviours influence demand. Scenarios from the g-Tech used in this analysis are not described in detail in this report, but greater information may be made available upon request.

Air Quality Benefits Assessment Tool (AQBAT)

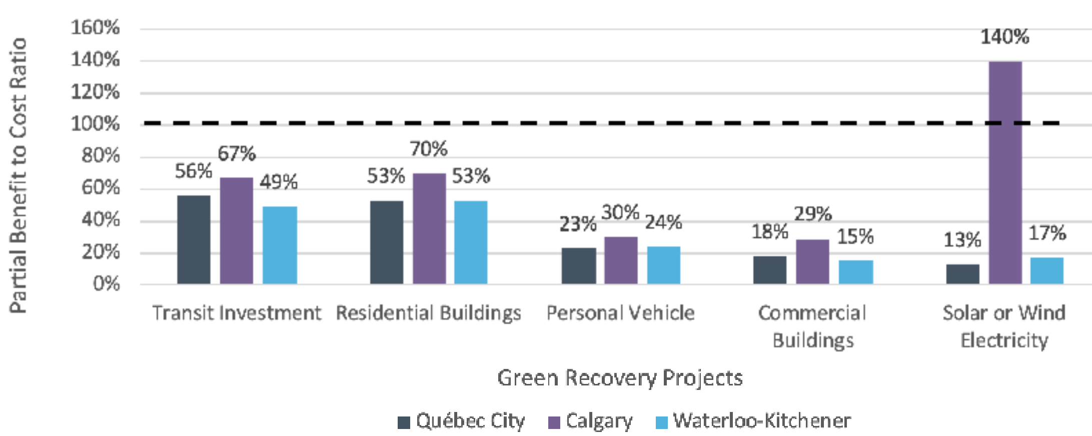
Health Canada's AQBAT modeling tool estimates the association between a change in population exposure to ambient air quality and associated health benefits or damages. It links pollutants, geographic areas, scenario years, and health points. Pertinent to this report, the AQBAT model relates the exposure of population-level air pollution to health outcomes and then estimates a monetary value from changes in exposure. Health impact information is presented in the form of concentration response functions which represents the risk associated with in air pollutant exposure for specific health endpoints. The nine health endpoints considered in this report are listed in the table below and are a subset of the full set of impacts included in AQBAT. The economic valuation of air pollution includes social, economic and public welfare consequences as key parameters.

RESULTS

Overall findings

The following section details the results from this screening analysis of the environmental and health benefits emerging from each investment. As detailed in Appendix 4, it is assumed that the $100 million in capital expenditures (costs) occurs in equal amounts between 2022 and 2025, with air quality benefits only accruing in the year after the initial expenditure. Emission benefits are estimated depending on the assumed capital life of the green investments which ranges from 15-30 years. The discussion of cumulative environmental and health benefits is followed by a breakdown of benefits within each of the three cities.

Figure 3: Summary of partial benefits-to-cost ratio for each project category across all cities



Renewable electricity projects in Calgary bring about the single highest overall level of benefit across all projects[67] and all regions. Benefits from solar or wind electricity investment in Calgary outperforms other projects across all regions in terms of both total and annualized benefit as well as from a benefit to cost ratio perspective. In fact, benefits from renewable energy projects in Calgary are 8 to 10 times higher than similar investments in Ontario and Québec, where electricity is largely decarbonized. Figure 1 shows that solar or wind projects in Calgary essentially pay for themselves, and then some, purely from the health and environmental benefits (that are assessed in this report) they bring about. This result is a clear reflection of the grid intensity of electricity in Alberta. Given the ongoing decarbonization in the electricity sector in Alberta, this benefit might fall in time, but it still represents an opportunity to capture substantial environmental and health benefits in a green recovery.

Overall, the project categories that deliver the highest level of annualized benefits across all three regions in terms of environment and health benefits are residential buildings and transit investments. Urban transit systems overwhelmingly rely on diesel fuel oil as their energy source, with over 90% of the fuel used in urban transit systems across Canada being diesel fuel[68]. Diesel combustion, believed to be one of the largest sources of environmental pollution, releases four main pollutants into the atmosphere, including $PM_{2.5}$ and NO_x[69]. In Canada, out of the total emissions attributable to transportation, heavy-duty diesel vehicles are the largest source of NO_x emissions and the second-largest source of $PM_{2.5}$ emissions[70]. Reducing diesel consumption through electrified transit investments therefore represents a critical opportunity to capture environmental and health benefits across all regions in a green recovery.

Overall, the project categories that deliver the highest level of annualized benefits across all three regions in terms of environment and health benefits are residential buildings and transit investments.

Table 5[71]: Results by Project Type (for $100 million in spending by project)

Type of Project	Location	Total Emission Reductions (tonnes)			Total Value (NPV @ 3%: $M 2020)				Annual Value ($M)
		CO2e	$PM_{2.5}$	NO_2	CO2e	$PM_{2.5}$	NO_2	Total	
Residential Buildings	Calgary	1,020,000	768	559	$52.60	$4.53	$0.08	$57.20	$2.92
	Waterloo-Kitchener	775,000	1,260	501	$40.10	$3.05	$0.13	$43.20	$2.20
	Québec City	643,000	2,980	607	$33.20	$9.79	$0.24	$43.30	$2.21
Commercial Buildings	Calgary	446,000	238	1,130	$23.10	$1.40	$0.17	$24.60	$1.26
	Waterloo-Kitchener	222,000	121	1,250	$11.50	$0.29	$0.33	$12.10	$0.62
	Québec City	269,000	134	1,310	$13.90	$0.44	$0.53	$14.80	$0.76
Solar or Wind Electricity	Calgary	2,070,000	82	3,110	$114.0	$0.58	$0.56	$115.0	$7.73
	Waterloo-Kitchener	258,000	14	541	$14.10	$0.04	$0.17	$14.30	$0.96
	Québec City	187,000	24	1,330	$10.20	$0.09	$0.64	$11.00	$0.74
Transit Investment	Calgary	635,000	3,620	2,910	$32.80	$21.40	$0.44	$54.60	$2.79
	Waterloo-Kitchener	669,000	2,130	2,790	$34.60	$5.15	$0.73	$40.40	$2.06
	Québec City	742,000	2,100	1,370	$38.30	$6.92	$1.10	$46.30	$2.36
Personal Vehicle	Calgary	333,000	605	487	$18.80	$4.73	$0.10	$23.60	$1.98
	Waterloo-Kitchener	322,000	310	405	$18.20	$0.99	$0.14	$19.30	$1.62
	Québec City	311,000	284	370	$17.60	$1.24	$0.20	$19.00	$1.59

The substantial benefits arising from retrofitting residential buildings is possibly attributable to the fact that a majority of Canadian homes rely on natural gas for energy especially for heating. In Alberta and Ontario, 89%[72] and 74% of the energy used for heating comes from natural gas[73]. Natural gas is a fossil fuel and its combustion releases $PM_{2.5}$ and NO_2. While Québec doesn't rely on natural gas for most of its energy or electricity needs, residential buildings in the province rely on wood burning[74], a major source of $PM_{2.5}$, to meet 33% of the province's home heating needs[75]. Potential benefits from investing in residential buildings could also be a function of the lower levels of energy efficiency in residential buildings. The cost of retrofitting a home is a major barrier that has prevented homeowners from updating their houses[76]. Additionally the adoption and enforcement of building codes has been lacking in the Alberta, Ontario and Québec. The National Building Code (NBC), which among other things, sets energy efficiency performance requirements for homes and small buildings. Neither Alberta nor Québec have adopted the latest (2017) version of the NBC and unlike British Columbia, none of the three provinces studied have adopted a provincial residential building code aligned with a net-zero emissions future. Furthermore, enforcement of building codes has been found to be negligible in Alberta and very limited in Ontario[77].

In all regions, the largest benefit derived is from GHG reductions, and to a somewhat lesser extent from particulate matter reductions leading to reduced adverse health impacts. The project category where health benefits come closest to parity with environmental benefits is for transit investments in Calgary, where health benefits form approximately 40% of overall benefits assessed. This may be a result of the projected trajectory of GHG reductions associated with each project in each region or may reflect stringent regulation of air pollution emissions in Canada relative to other countries.

Projects with high environmental benefits generally offer higher relative health benefits as well, given that significant reductions in fuel consumption are likely to yield substantial air quality improvements. This analysis shows that the majority of health-related benefits across projects arise from reductions in $PM_{2.5}$, with health benefits associated with reductions in NO_2 being relatively limited across projects and regions. As an example, NO_2 reduction in Québec city from retrofitting commercial buildings is somewhat close to NO_2 reductions achieved from transit investments. However, these reductions do not translate to significant benefits in terms of total value. Therefore, this screening analysis shows that reducing GHG emissions and mitigating $PM_{2.5}$ offers the biggest bang for the buck when compared with NO_2 emissions. It bears mentioning that the assessment on the relative value offered by $PM_{2.5}$ versus NO_2 emissions doesn't take into account the knock-on air quality or GHG impacts either might have. For example, NO_x emissions affect ground-level ozone, a factor not considered in this analysis.

Investments in commercial buildings and personal vehicles offer the lowest benefit across all regions. This finding is contrasted with the popularity of the measures, since both project types are very popular and were put forward in a majority of the green recovery reports reviewed for this analysis. For commercial buildings, lower levels of benefits are a function of the high efficiency of commercial boilers, the relatively lower air pollutant emissions intensity per unit of energy, and the low level of emission reductions that can be attained through deep decarbonisation retrofits[78]. In the case of personal vehicles, the relatively lower value of benefits could be attributable to the fuel efficiency standards which have established progressively more stringent GHG emission standards on new light-duty vehicles starting 2011[79].

Regional Findings

Calgary

Overall benefits

Table 6: Calgary: Summary of environmental and health benefits

Calgary	Annualized Benefit ($M)*	Total Benefit (NPV @3%: $M)	Partial Benefit Cost Ratio
Solar or Wind Electricity	$7,730	$115.0	140%
Residential Buildings	$2,918	$57.2	70%
Transit Investments	$2,786	$54.6	67%
Personal Vehicle	$1,255	$24.6	30%
Commercial Buildings	$1,977	$23.6	29%

A comparative assessment of the NPV of benefits (the sum of discounted stream of benefits over the life of the projects) shows that for Calgary, benefits from investing in solar and wind energy projects is in the order of 2 to 5 times larger than the other investments. These benefits from renewable energy projects significantly outperform the costs, even without taking into account savings from operational expenditures and such that are out of scope for this analysis, but would further the economic case for investment. Similarly, investing in transit decarbonization and retrofitting residential buildings offers significant monetary value for Calgary. These projects recoup costs simply from the health and environmental benefits they bring about from local air quality improvements from reducing two select CACs and reducing GHGs. While in the case of renewable energy and residential buildings, the two project categories with the highest overall benefits associated with deployment, value is primarily derived from carbon reduction, in the case of transit, significant value in terms of health benefits is also gained from reduction in $PM_{2.5}$ levels.

* Equivalent annual cost calculated @ 3% and assuming the lifespan of each project.

Environmental benefits

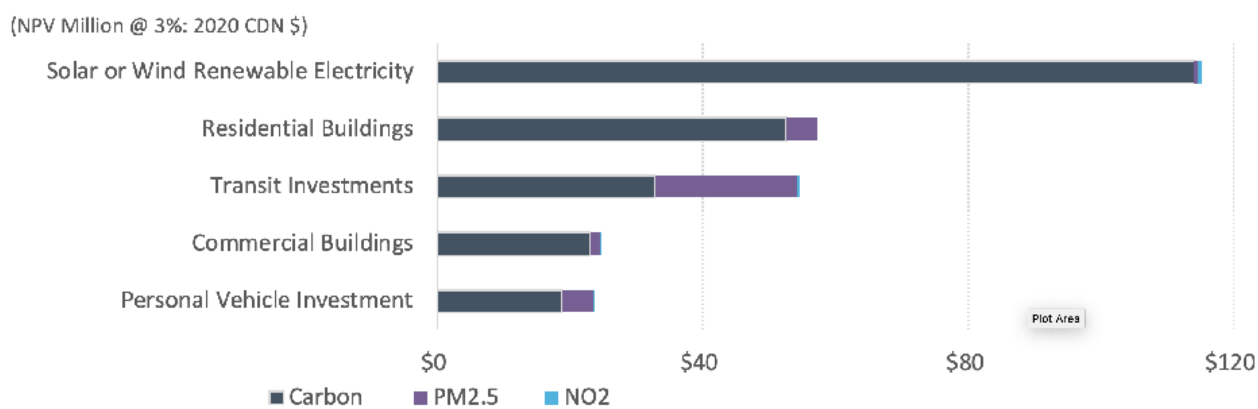
The province of Alberta holds the unenviable spot of being the largest GHG emitting province in Canada, owing in large part to its oil and gas industry[80]. Alberta relies on coal and natural gas to meet approximately 91% of the province's electricity needs[81]. Given the make-up of the electricity grid, it is perhaps unsurprising that out of the five green recovery projects analysed, the largest environmental benefits for Calgary come from investing in renewable energy projects in solar and wind. Second to renewable energy investments, it is investments in improving the energy efficiency of residential buildings, which accounts for more than 30% of the city's emissions, that will bring about the largest environmental benefits for Calgary[82].

Table 7: Calgary: GHG and Air Quality Tonnes Reduced (lifetime)

Calgary	Lifetime Emission Reductions (tonnes)		
	CO_2e	$PM_{2.5}$	NO_2
Residential Buildings	1,020,000	768	559
Commercial Buildings	446,000	238	1,130
Solar or Wind Electricity	2,070,000	82	3,110
Transit Investments	635,000	3,620	2,910
Personal Vehicle	333,000	605	487

Health benefits

Figure 4: Calgary: GHG and Air Quality Benefits



Gven the make-up of (Alberta's) electricity grid, it is perhaps unsurprising that out of the five green recocevry projects analysed, the largest environmental benefits for Calgary come from investing in renewable energy projects in solar and wind.

From a local air quality and health perspective, transit investments hold the largest benefit for Calgary. Diverting transit away from diesel will reduce large amounts of particulate emissions, which will trigger improvements in local air quality. Currently, Alberta's transport sector contributes 1.26% and 24.9% of the province total $PM_{2.5}$ and NO_x emissions respectively[83]. Air quality in downtown core Calgary is impacted by traffic emissions, in addition to industrial emitters and activity from a major airport[84].

Investments in renewable energy projects also significantly reduce NO_2 emissions from natural gas use. In 2018, Alberta's electricity sector was responsible for releasing $PM_{2.5}$ and NO_x emissions, which totaled at 0.26% and 8.3% of total provincial emissions, respectively[85]. While the NO_2 reduction resulting from adopting renewable energy projects is not identified as a significant driver of health outcomes, the steep decline in GHG emissions that results has substantial environmental benefits that may also improve health outcomes through avoided impacts from a changing climate[86].

Québec City

Overall benefits

Getting zero-emissions public transit vehicles on the road and improving the energy efficiency of residential buildings are the two project categories that offer the largest overall benefits to

Québec City residents through improved air quality and reduced GHG emissions. The key difference between investing in projects aimed at reducing emissions from residential buildings and transportation is that while the former offers larger air quality improvement, the latter brings forth larger carbon reductions. These two projects bring about 2 to 4 times the benefit, in terms of NPV, when compared to investments in personal vehicle, renewable energy, and commercial buildings-related projects. Additionally, transit and residential buildings show promise when considering the value derived simply in terms of health and environmental benefits relative to costs.

Table 8: Québec City: Summary of Benefits

Québec City	Annualized Benefit ($M)*	Total Benefit (NPV @3%: $M)	Partial Benefit Cost Ratio
Transit Investments	$2,362	$46.30	56%
Residential Buildings	$2,209	$43.30	53%
Personal Vehicle	$1,592	$19.00	23%
Commercial Buildings	$755	$14.80	18%
Solar or Wind Electricity	$739	$11.00	13%

Table 9: Québec City: GHG and Air Quality Tonnes Reduced (lifetime)

Québec City	Lifetime Emission Reductions (tonnes)		
	CO_2e	$PM_{2.5}$	NO_2
Residential Buildings	643,000	2,980	607
Commercial Buildings	269,000	134	1,310
Solar or Wind Electricity	187,000	24	1,330
Transit Investments	742,000	2,100	1,370
Personal Vehicle	311,000	284	370

Like Calgary, overall gains from transit and residential building related investments are primarily attributable to carbon reductions and, to a somewhat lesser extent, to health benefits arising from lower concentrations of particulate matter in ambient air. However, in sharp contrast to Calgary, solar or wind electricity projects offer the least value to Québec city. Québec's electricity grid is almost entirely decarbonized and more than 90% of the province's energy comes from clean sources. Therefore, the analysis finds few emissions reductions from renewable energy projects[87].

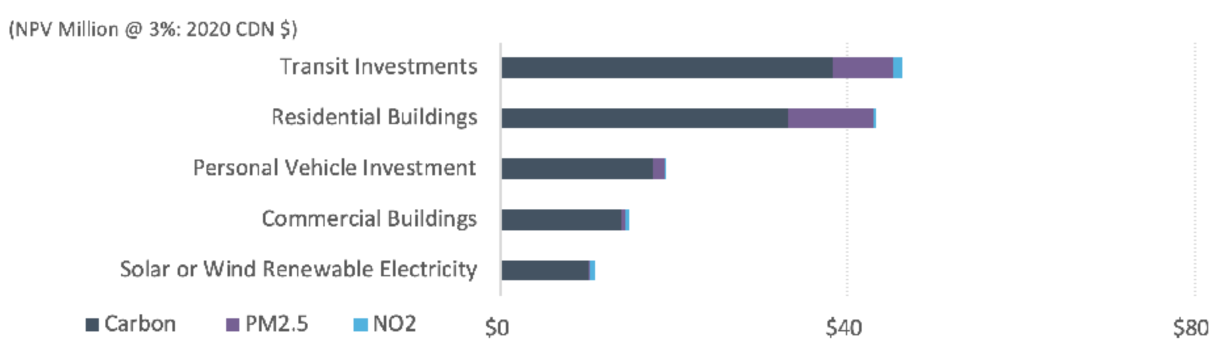
Environmental benefits

Transportation accounts for more than 40% of Québec's GHG emissions and is a primary concern for advancing climate action in the province[88]. Accordingly, this analysis shows that investing in transit related green recovery projects brings about the steepest carbon reductions for Québec City across all project categories, whereas renewable energy projects offer the smallest amount of carbon reductions. Second to transit investments, greatest carbon reduction will be brought about by retrofitting residential buildings, which continue to use wood burning for heating in the province.

Health benefits

Québec's transportation sector accounts for 4.6% and 69.3% of the province's total $PM_{2.5}$ and NO_x emissions respectively[89]. Similarly, the buildings sector in Québec is an important source of air pollution, with commercial, residential, and institutional buildings releasing $PM_{2.5}$ and NO_x emissions totaling 32.3% and 7.2% respectively in 2018[90]. Therefore, from a purely air quality perspective, investing in transit and residential buildings offers the most benefits primarily from reductions $PM_{2.5}$, and to a lesser extent from reductions in NO_2.

Figure 5: Québec City: GHG and Air Quality Benefits



* Equivalent annual cost calculated @ 3% and assuming the lifespan of each project.

Waterloo-Kitchener

Overall benefits

Residential buildings and transit offer the highest overall value to the Waterloo-Kitchener region. The value proposition of investing in residential buildings and transit can be seen in the benefit to cost ratio of these investments. 53% of the costs incurred to upgrade and retrofit residential buildings will be recovered in terms of the environmental and health benefits arising from air quality improvements and GHG reduction. For transit investments, this figure stands at 49%.

When compared to commercial buildings, which are associated with the lowest level of benefit given the high efficiency of commercial boilers and the small relative improvement that can be gained through decarbonization, residential buildings offer about 2 to 3 times more environmental and health benefits. Solar or wind electricity investments also offer limited value. Ontario's $PM_{2.5}$ and NO_x emissions from electricity power generation only comprised of 0.11% and 2.45% of total emissions in 2018, respectively[91]. In 2016, Ontario generated 91% of its electricity from "sources that are non-emitting during operation", making generation relatively clean in the province[92]. Like Calgary and Québec City, benefits from green recovery investments are primarily attributable to GHG reduction and reductions in particulate matter.

Table 10: Waterloo-Kitchener: Summary of Benefits

Waterloo-Kitchener	Annualized Benefit ($M)*	Total Benefit (NPV @3%: $M)	Partial Benefit Cost Ratio
Residential Buildings	$2,204	$43.20	53%
Transit Investments	$2,061	$40.40	49%
Personal Vehicle	$1,617	$19.30	24%
Solar or Wind Electricity	$961	$14.30	17%
Commercial Buildings	$617	$12.10	15%

Table 11: Waterloo-Kitchener: GHG and Air Quality Tonnes Reduced (lifetime)

Waterloo-Kitchener	Lifetime Emission Reductions (tonnes)		
	CO_2e	$PM_{2.5}$	NO_2
Residential Buildings	775,000	1,260	501
Commercial Buildings	222,000	121	1,250
Solar or Wind Electricity	258,000	14	541
Transit Investments	669,000	2,130	2,790
Personal Vehicle	322,000	310	405

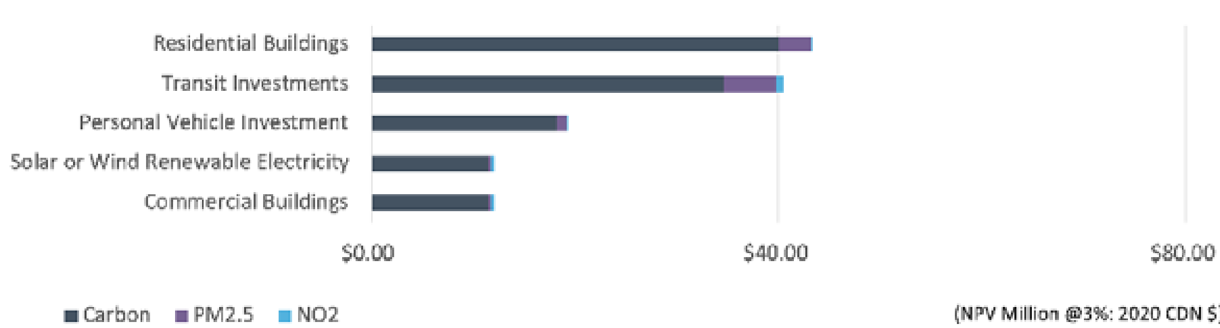
Environmental benefits

Residential buildings bring about the largest carbon reduction in the region. Residential buildings in the Waterloo region account for 18% of the region's GHG and air pollutant emissions. [93] Transportation makes up for 49% of the region's total emissions[94]. Accordingly, recovery projects decarbonizing public transit bring about the second largest carbon reductions in the region.

Health benefits

Out of the three regions analyzed for this report, Waterloo-Kitchener has the lowest levels of $PM_{2.5}$ and NO_2 concentration in ambient air. While residential buildings offer the steepest carbon reductions, it is transit investments that bring about the largest air quality benefits. This is unsurprising given that transportation is the single largest source of NO_x emissions in Ontario, whereas the residential sector, followed by transportation are the two largest sources of $PM_{2.5}$ and NO_x emissions[95]. While investment in commercial buildings will significantly reduce the region's NO_2 emissions, this doesn't translate into actual benefit in terms of monetary value.

Figure 6: Waterloo-Kitchener: GHG and Air Quality Benefits



RECOMMENDATIONS

Informed by the analysis and findings detailed above, the following three recommendations can help policymakers credibly integrate health and environmental considerations into spending decisions in a green recovery context.

Recommendation 1: Cost-Benefit analysis of green recovery investments should consider gains from health benefits, in addition to environmental benefits

One key takeaway that has emerged from the analysis is that health outcomes from air pollution improvements are important and can significantly enhance the overall value proposition of green recovery projects. Decision-makers and key stakeholders should comprehensively demonstrate and understand the potential benefits from allocating funds towards green recovery projects that come from factoring in changes in air quality, amongst other environmental factors that influence health outcomes. While an analysis is sometimes conducted under federal regulations specific to air pollution or otherwise explicitly targeting carbon mitigation[96], an evaluation of potential health impacts is yet to become standard practice when deciding on whether to green-light investments in an economic recovery project. This is especially true at the provincial level. Policymakers should consider potential health benefits in economic recovery decision-making, a factor that is especially relevant given the variance in outcomes between projects and regions that was seen between projects in this analysis.

One key takeaway that has emerged from the analysis is that health outcomes for air pollution improvements are important and can significantly enhance the overall value proposition of green recovery projects.

Recommendation 2: Recovery spending decisions should be place-specific and should consider health and environmental outcomes for local communities

Local context matters, and policymakers should consider this unique regional context when making decisions about recovery spending. From the analysis, no region exemplifies this argument more than Calgary. While overall, investing in decarbonizing transit and retrofitting residential buildings promise the highest benefit, solar or wind energy investments far outpace other green recovery projects in terms of environmental and health benefits. Alberta's distinct energy mix, when compared to Ontario and Québec, makes investing in renewable energy much more attractive from an environmental and health perspective than other options. This shows that simply because a project seems logical or has been successful in other jurisdictions, does not necessarily mean that it will be the right choice for other regions too. Moreover, different projects bring about varying degrees of GHG and air pollution improvements for different regions. While in some cases, improvements in air pollution are comparable to GHG reductions, as was the case with transit investments in Calgary. In other cases, such as with residential buildings in Waterloo-Kitchener, gains from GHG reductions might be several times larger than the available gains from air quality improvements.

Recommendation 3: Recovery projects that offer the highest benefits in terms of health and environmental impact should be prioritized over others

In the context of the economic setback due to COVID-19, stakeholders across the board have laid out a plethora of project options that governments can take forward to help the economy recover. The reality, however, is that in light of budgetary constraints, or perhaps even political hurdles, investing in all the projects stakeholders have called for is unfeasible. Accordingly, a cost-benefit analysis, which factors in health and environmental gains, can act as a prioritization tool and narrow down the range of options for decision-makers. In many ways, this sort of an exercise can complement other decision-making tools already in place at the provincial-level. Even a partial cost-benefit analysis, such as the one conducted for this report, supports greater integration of the health benefits of recovery spending into decision-making. From this analysis, projects can be selected that offer the highest overall level of benefits for communities, thereby ensuring that recovery dollars offer a range of benefits to community members[97].

CONCLUSION

In view of an economic recession triggered by COVID-19, government spending to stimulate growth and rejuvenate the economy is necessary. Investing in recovery projects that further Canada's climate goals while also improving health outcomes offers a real opportunity to tangibly support front-line communities hardest hit by this dual economic and health crisis. The pertinent question to be asked in this context is - which green recovery projects offer the best shot at stimulating growth and improving health and environmental outcomes? This report answers this question by taking a place-specific approach that takes into account regional characteristics such as existing levels of pollution, and the energy mix at play, among other factors. The report evaluates five green recovery project categories that have prominently featured in recovery discussions and analyzes the comparative value each offers to three Canadian cities, namely Calgary, Québec City, and Waterloo-Kitchener. The value or the relative benefit each project holds for each city is expressed in terms of benefits arising from improved air quality and reduced GHG emissions. The analysis shows that for Calgary investing in solar or wind electricity projects offers the most value, whereas for Québec City and Waterloo-Kitchener investing in decarbonizing public transit and improving the energy efficiency of residential buildings will bring about the greatest improvement in air quality and GHG emissions. Critically, the analysis demonstrates two key points. First, there is a strong economic case for investing in green recovery projects given the substantial health and environmental gains they bring about. Second, local context matters, and policymakers must take into account their regional context when deciding on recovery spending.

Investing in recovery projects that further Canada's climate goals while also improving health outcomes offers a real opportunity to tangibly support front-line communities hardest hit by this dual economic and health crisis.

This report sets the stage for future discussions on potential benefits of green recovery projects not only between, but within communities as well. The effects of the pandemic have been very unevenly distributed, with vulnerable and marginalized individuals and communities bearing disproportionate economic and health costs[98]. Identifying the health benefits associated with specific projects can help policymakers better understand which projects could offer significant benefits to which communities or groups, improving their capacity to target spending towards areas that could benefit the most from projects that reduce emissions and improve health outcomes for vulnerable communities. This, in turn, can ensure spending is directed towards projects that offer the greatest potential benefits to an even larger number of Canadians.

APPENDIX 1: GREEN RECOVERY REPORTS REVIEWED IN THIS ANALYSIS

To identify prominent green recovery projects that were advanced in recovery discussions in Canada in the aftermath of the COVID-19 pandemic, a comprehensive literature review was conducted. All recovery reports published between March – November 2020, by leading environmental organizations from both within and outside Canada were reviewed. The 13 reports which were studied as part of this literature review are listed below and include prominent national reports and a few international examples that were frequently referenced in Canadian economic recovery discussions.

Table 12: Green recovery reports analyzed for this report

Report title	Publishing organization	Region
Assessment of Green Recovery Plans after COVID-19	We Mean Business Coalition	International
Bridge to the Future	Task Force for a Resilient Recovery	National
Building back better: A synthesis report	Corporate Knights	National
Canada's Green Building Engine	Canadian Green Building Council	National
Green Stimulus	Pembina Institute	National
Green Strings	International Institute for Sustainable Development (IISD)	National
Greening the Recovery	International Monetary Fund (IMF)	International
Healthy Recovery Plan	Canadian Association of Physicians for the Environment (CAPE)	National
Jobs for a strong and sustainable recovery	London School of Economics	International
Making the Green Recovery Work	Organization for Economic Cooperation and Development (OECD)	International
Recommendations for recovery and budget actions	Green Budget Coalition	National
The Case for a Green and Just Recovery	C40 Cities	International
Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?	Smith School of Enterprise and the Environment, Oxford University	International

From this list of 13 reports, a qualitative assessment of the projects contained in this list was conducted. The projects selected from this list had to meet three criteria to merit inclusion within this report's analysis:

- **Appear in at least 50% of reports** to indicate broad support;
- **Be a "project/action" (i.e. a project/technology)**, not a "measure" (i.e. fiscal incentive, policy or regulatory measure). This is due to the uncertainty around the volume of action that can be causally linked to a particular measure;
- **Impact needs to be measurable.** This was evaluated by including only mature technologies, or actions for which credible air pollution emissions assessments have been conducted in the past.

APPENDIX 2: HOW DO REPORTS PROPOSE THESE PROJECTS GET ADVANCED?

The list of projects identified in this report represents those most frequently advocated for in green recovery reports. This appendix offers an overview of how different reports advocate that these technologies be supported to achieve growth and environmental objectives in a green recovery, and offers differing levels of detail on policy instruments and implementation depending on what is proposed in reports.

Zero-emissions transportation projects

The overarching objective of supports for ZEV uptake advanced in reports are that ZEVs and ZEV charging infrastructure should be accessible in every Canadian province and territory[99]. A number of measures are called for to support greater uptake of zero-emissions personal and public transit vehicles. Reports typically call for three types of measures: Incentivizing direct purchases of ZEVs; improving accessibility for purchasing vehicles; and, supporting greater build-outs of charging infrastructure. These apply to both personal and public transit ZEVs.

Incentive programs are commonly identified as a policy tool to encourage the purchase and use of ZEVs for both personal and public transportation. Incentive programs can include purchase rebates or tax credits for those who purchase a ZEV[100]. Some green recovery reports propose that incentive programs include a scrappage incentive for personal vehicles, meaning that those who turn in a internal combustion engine vehicle for a ZEV would recieve a cash rebate[101]. The objective of scrappage programs is to increase the number of ZEVs on the road, while simultaneously decreasing the number of vehicles powered by internal combustion engines on the road. Scrappage programs can be targeted towards supporting asset turnover amongst older vehicle stock, meaning they offer a potential opportunity to get higher-emitting older vehicles off the road[102].

Reports also advocate for the installation of charging infrastructure including urban charging infrastructure for personal and public transit vehicles, and charging infrastructure for long-haul freight transportation. Reports advocate for support through a combination of grants and interest free loans from the Canadian government to help fund the necessary electrical grid upgrades to accommodate charging infrastructure[103]. Many green recovery plans emphasize the need for filling personal ZEV charging gaps by installing charging stations along the Trans-Canada Highway[104]. This aligns with reports calling for the federal government to invest in filling the gaps along major highway networks throughout the country with high-speed charging infrastructure in convenient locations[105].

Clean energy projects

Reports advocate that greater deployment of solar PV and wind turbines be supported through three mechanisms in green recovery reports: Investing in electricity transmission and distribution infrastructure; supporting the deployment of energy storage technologies to store electricity for peak hours; and improving accessibility of technologies in remote or off-grid locations. Some of these mechanisms involve direct financial support for generation assets, while others upgrade electricity infrastructure to permit greater installation of solar and wind generation assets.

Improvements to electrical grids, transmission infrastructure, and storage capabilities must be made to support greater integration of small-scale renewable electricity generation onto and across provincial grids[106]. Reports propose financing improvements in transmission connectivity between and within provinces through incentive programs that pool private and public sector funding. Some reports advocate for federal incentives for provinces to construct inter- and intra-provincial transmission lines, which could also entice further private investment in the near term. Other reports cite specific regional needs for improvements to transmission lines and infrastructure across in the prairie provinces, which are singled out due to their high wind and solar energy generation potential[107].

Advancements to energy storage infrastructure are another mechanism that several reports have proposed as a method to support renewable energy installations. Many locations in Canada that have access to renewable energy sources do not have sufficient energy storage, and stakeholders have identified that this lack of storage has slowed or limited uptake[108]. Reports called for federal investment over the next decade to improve energy storage technology. Finally, improved accessibility of renewable energy sources to all Canadians is proposed through incentive programs and financing supports, including grants, to support decarbonization in rural and remote communities who are reliant on diesel powered electricity generators.

Energy efficient buildings and retrofit projects

The reviewed green recovery reports advocate for deep energy efficiency retrofits for three building sectors: Commercial buildings; multi-unit residential buildings; and, residential homes. Green recovery reports highlight federal investment programs and tax incentive plans as the two primary mechanisms to make energy efficiency retrofits more accessible across Canada[109].

Nation-wide investment in deep retrofits for existing buildings, paired with the provision of federal grants and loans to cover large portions of retrofitting costs, are advocated for as necessities to advance deep retrofits at scale[110]. Upfront federal investment from other institutions in retrofitting programs are identified as being needed to catalyze the Canadian market for deep retrofits[111]. Reports note that programs could then shift to federal interest-free loans, or co-financing programs between governments and households, as the necessary workforce and supply chains developed to carry out retrofits on a broader scale[112]. Reports also recommend that investments should be tied to newly stringent energy efficiency standards to ensure regions and provinces are setting and meeting ambitious GHG targets[113]. This will also further promote the extended use of deep retrofits to accomplish these goals.

It has also been suggested that the Canadian government and provincial governments should establish tax incentives for commercial and residential buildings, and homes that undergo retrofits to improve energy efficiency[114]. An example of this provided by the International Monetary Fund (IMF) is a tax on buildings that generate high emissions and a rebate of that revenue to buildings with lower emissions that meet national standards[115]. Reports noted the introduction of investment and tax-incentive programs could further support expanding deep retrofits across commercial and residential buildings, and homes[116].

APPENDIX 3: METHODOLOGY USED TO SELECT CITIES IN THIS ANALYSIS

The three communities examined in this report (Calgary, Alberta; Québec City, Québec; and Kitchener, Ontario) were selected for this analysis using the following methodology.

First, a screening assessment was conducted to identify which cities across Canada met the following criteria:

- **Included in the 2016 census' "top 20 cities in Canada by population size" list**: Larger population centers tend to have larger population health impacts. If a city's population is too small, health impacts risk being negligible due to a lack of pre-existing built infrastructure whose emissions could be reduced. Accordingly, this step is essential for comparing the relative benefits offered from services like electrified public and transit and improved energy efficiency in buildings. These figures were taken from the 2016 census to facilitate comparisons across cities and regions.

- **Included in Top 20 cities with highest average ambient concentrations of $PM_{2.5/10}$ and surface-level ozone:** While the scope of this analysis is broader than these three pollutants, concentrations of these pollutants were used as proxies for overall air quality in this screening exercise. This data was taken from Environment and Climate Change Canada's *2018 Air Quality Indicators Report* (Environment and Climate Change Canada, 2018).

These screening criteria left the following cities that counted in top 20 in both categories, shown below in Table 3 categorized by population size (over 1 million residents, 500,000 – 1,000,000 residents, and <500,000 residents)[117]:

From these eleven cities listed, four provinces are represented: Ontario, Québec, Alberta and Saskatchewan. A decision was made to have one city from each province where more than one city was represented included in this analysis to ensure regional variance. This means that the final choice of cities would require representation from Ontario, Québec and Alberta.

Calgary was selected in lieu of Edmonton due to the city's marginally larger population and because, between the economic performance of the two cities in 2019 and 2020, Calgary's economy was the only one that experienced real GDP growth in 2019[118], and had a comparatively smaller decline in real GDP growth (-10.1% to -10.6%) in 2020[119]. Given that Calgary has over 1 000 000 residents, it was identified as the city with >1 000 000 residents scoped within this analysis. With this selection, the only remaining city identified through this screening analysis in the province of Québec was **Québec City**, which was selected as the city whose population was between 500,000 < 1 000 000 residents. This left a city from Ontario to occupy the slot of cities under 500,000 residents, and **Kitchener** was selected due to the size of its economy. From the four Ontario cities in this analysis with <500,000 residents, Kitchener has the largest overall GDP[120].

It is important to note that the criteria used to differentiate between cities within this report did not yield significant variance, since measures of population size and economic performance were often very comparable or yielded marginal differences. Ultimately, the decision to select certain cities was the author's decision based on the factors outlined above, and this report recognizes that selecting alternative cities would also yield meaningful insights on health effects.

Table 13: Cities identified through screening criteria, categorized by population

<500,00 residents	500,000 – 1,000,000 residents	>1,000,000 residents
Kitchener, ON (470,015)	Québec City, QC (705,103)	Toronto, ON (5,429,524)
London, ON (383,437)	Hamilton, ON (693, 645)	Montreal, QC (3,519,595)
Oshawa, ON (308,875)		Calgary, AB (1,237,656)
Windsor, ON (287,069)		Edmonton, AB (1,062,643)
Regina, SK (214,631)		

APPENDIX 4: INDICATORS USED FOR ANALYSIS

This report uses four separate sets of indicators:

1. **Lifetime emission reductions**: The calculated CO_2e, NO_2 and $PM_{2.5}$ emissions reductions for each project over its capital life. Residential, commercial, and transit capital investments have a 30-year life; the personal vehicle investments are 15 years; and solar and wind investments have a 20-year life.

2. **The Net Present Value (NPV) of the benefits**: The sum of the discounted stream of benefits over the life of the equipment expressed in constant 2020 dollars, where,

$$\mathrm{NPV}(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

R_t = the value of the benefit in time, t.

i = 3% discount rate

t = is time and varies by project type

3. **Annualized benefit**. The annualized benefit is calculated as equivalent annual cost (EAC) in constant 2020 dollars, which is a way to compare each project with differing time spans against one another on an annualized basis. The equivalent annual cost is calculated as:

$$\mathrm{EAC} = \frac{\mathrm{NPV} \times i}{1 - (1 + i)^{-t}}$$

NPV = the NPV of all benefits by project type.

i = 3% discount rate

t = is time and varies by project type

4. **Partial Benefit Cost Ratio:** An estimate of the partial benefit cost ratio, with a value of greater than one indicating the project is welfare maximizing, or efficient. This estimate is partial because it does not include a whole series of other green recovery benefits, we would expect from these expenditures such as energy and operational savings, and avoided time spent at gasoline stations. The ratio is calculated as the net present value of the benefits over the net present value of the costs. It is assumed that the $100 million in capital expenditures (costs) occurs in equal amounts between 2022 and 2025, with benefits only accruing in the year after the initial expenditure.

APPENDIX 5: LIMITATIONS OF ANALYSIS

This report analyses the comparative value of some of the health and environmental benefits that could be captured by implementing five different green recovery projects across three regions cities. The analysis is subject to three key limitations.

First, this report is limited in scope to the assessment of air quality and GHG benefits emanating from two pollutants i.e. $PM_{2.5}$ and NO_2. It does not consider the health benefits arising from other pollutants such as SO2, ozone, black carbon and SLCFs etc. An analysis that considers other additional pollutants will likely result in different overall benefit calculations.

Second, while emissions intensity of energy demanded to power new projects and the baseline air quality index is accounted for in the models used, it doesn't take into account the use-patterns of a given project or the indirect equity impacts of the project on different members of a community's population. For example, abatement from transit investments is subject to continued mass use of public transit options by local communities and either a maintenance or expansion of transit routes.

Second, this report estimates the emissions reductions from green recovery investments. To this end, the abatement costs considered i.e. the project costs, include only the capital investments and do not include ongoing operational costs and savings. Typically, almost all green recovery projects will lead to substantial net energy cost savings reducing the overall abatement cost. However, as this project is specifically trying to measure the impact of the capital expenditure of green recovery projects, these net operational benefits (such as cost savings) are not included. A major source of unquantified benefit is therefore not included in this study.

Third, the g-Tech model results have a significant degree of uncertainty related to whether new incremental capital investment in low-carbon technology identified in the model would perform similarly to the actual green recovery projects implemented. There is a strong argument here to say that it is. A wide range of technology solutions are included in the model thereby minimizing the chance that the actual green investments would not be reflected. For example, in the residential sector, the model reflects solutions for improving the energy efficiency of building shells, improving furnace efficiency, and decarbonizing energy sources above the existing reference case which is also improving in time.

APPENDIX 6: OVERVIEW OF AIR QUALITY ANALYSIS CONDUCTED FOR THIS REPORT

The method used in this study to translate emissions changes into air quality changes relies on the following simplified relationship for the air pollutants evaluated in this study:

$$\frac{\Delta C}{C_{\mathrm{L}}} = \frac{\Delta E_L}{E_L}$$

Where:

= Change in concentration of air pollutant in census division – ppb for NO_x or µg/m^3 for $PM_{2.5}$

= Local concentration of air pollutant in census division (i.e., reported concentration minus background concentration) - ppb for NO_x or µg/m^3 for $PM_{2.5}$

= Change in urban emissions of air pollutant (tonnes) – this is estimated using the gtech model.

= Total urban emissions of air pollutant (tonnes) – these are estimated from GHG emissions inventories developed by the municipality.

As noted in the main text of this report, published emissions and concentration trends show a reasonably linear relationship between emissions and concentrations for pollutants such as SO_2 and NO_2. This sort of approach has been used in a number of previous studies, including IISD's Costs of Pollution in Canada and Transport Canada's Evaluation of Total Cost of Air Pollution Due to Transportation in Canada. However, it has not been peer reviewed. It is not intended to be considered a rigorous model; rather, to provide a conceptual framework to assist in policy at a screening level.

Sources of uncertainty have been identified in the main report. However, the quantification of uncertainty (and its associated confidence level) is considered outside of the scope of this report. There are a number of factors that this simplified approach does not account for and therefore contribute to the uncertainty in the air quality assessment. Some of these factors are outlined below:

- The transport of pollutants downwind from the source census division to the receptor census division. The presented approach is therefore expected to over-estimate the benefits to receptors in the upwind portion of the census division and under-estimate benefits to receptors outside of the census division.
- Non-linear relationships between evolved $PM_{2.5}$ concentrations and the emitted gaseous precursors to $PM_{2.5}$ (e.g., NO_2, SO_2 and ammonia). Regional airshed modelling with all precursor pollutants would be required to determine whether the presented approach is an overestimate or underestimate of air quality benefits. This level of modelling was considered outside of the scope of this study.
- Air quality benefits from SO2 and ozone have not been evaluated. The presented approach is therefore expected to underestimate air quality benefits in the study regions.

In general, we believe that the air quality assessment approach presented in this paper is a conservative estimate (i.e., underestimate) of the air quality benefits that could be expected from these green investments.

ENDNOTE CITATIONS

1 Refer to Appendix 4 for details on how the partial benefit to cost ratio was calculated
2 Senate of Canada, 2018.
3 Leyl, 2021
4 CAPE, 2020
5 Carozzi & Roth, 2020
6 The list of 13 green recovery reports reviewed for this report are listed in Appendix 1. The green recovery projects that have been studied in this report have been derived from this universe of 13 green recovery reports published between March and November 2020.
7 Discussion of the epidemiological evidence of negative health impacts associated with exposure to $PM_{2.5}$ and NO_2 is discussed in later sections of this report.
8 An explanation of the g-Tech, a general equilibrium model operated by Navius Inc, is provided later in this report, along with additional rationale for the selection of these two pollutants.
9 Examples of projects include improving the energy efficiency of multi-unit residential buildings, and electrifying public transit vehicles
10 Edger et al. 2020.
11 Natural Resources Canada, 2019.
12 Cluett R. & Amann J., 2014.
13 Ibid.
14 Natural Resources Canada, 2019.
15 Edger et al. 2020; Pembina 2020; Torrie et al. 2020.
16 Torrie et al., 2020.
17 Environment and Climate Change Canada, 2006
18 Krishnan & Panacherry, 2018; Xu et al., 2020; Zhang et al., 2015.
19 World Health Organization, 2013.
20 Krishnan & Panacherry, 2018; Zhang et al., 2015.
21 Zhang et al., 2015.
22 Bero Bedada et al., 2016; Khaniabadi et al., 2017; Krishnan and Panacherry, 2018.
23 Abel et al., 2018; Bedada et al., 2016; Khaniabadi et al., 2017; MacNaughton et al., 2018; Ran et al., 2018.
24 It bears mentioning that this analysis excludes and does not consider the health benefits arising from other pollutants such as SO2, ozone, black carbon and SLCFs etc. An analysis that considers other additional pollutants might result in larger overall benefit calculations.
25 An overview of the g-tech is provided in Box 3.
26 Abel et al., 2018; Cui et al., 2020; Loughner et al., 2020; P. Yang et al., 2019; Raifman et al., 2020; Ramaswami et al., 2017; Schraufnagel et al., 2019; Sicard et al., 2019.
27 Perera, 2017; Schraufnagel et al., 2019.
28 MacNaughton et al., 2018
29 Colton et al., 2015
30 Wilson et al. 2014.
31 Perera, 2017; Public Health Ontario, 2015.
32 Abel et al., 2018; Cui et al., 2020; MacNaughton et al., 2018; Merklinger-Gruchala et al., 2017; Nieuwenhuijsen and Khreis 2018; Ou et al. 2020; Perera, 2017; Xue et al. 2015; J. Zhang et al. 2019; Zhang et al., 2015.
33 Abel et al., 2018.
34 Partridge and Gamkhar 2012.
35 Ibid.
36 Espin-Perez et al., 2018; Jennings et al., 2020; Peters et al., 2020; Public Health Ontario, 2015; Ren et al., 2016; Xia et al., 2015; Xiongzhi Xue et al., 2015; Zhang et al., 2015.
37 Evans, 2019; Min et al., 2018; Munzel et al., 2017a; Nieuwenhuijsen & Khreis, 2018.
38 Peters et al., 2020.
39 Peters et al., 2020.
40 Shin et al. 2012; Williams et al. 2018; Wolkinger et al. 2018
41 Peters et al., 2020.
42 US EPA 2016; US EPA 2019.
43 US EPA, 2015.
44 Health Canada, 2021.
45 M. Liu et al., 2019; Munzel et al., 2017b.
46 Munzel et al., 2017b; B.Y. Yang et al., 2018; Molemaker et al., 2012; Sicard et al., 2019; Xu et al., 2020.
47 Chen et al. 2018; Villeneuve et al. 2013.
48 Ran et al. 2018; Molemaker 2012; Public Health Ontario 2015; Villeneuve et al. 2013; Yang et al. 2018.

49 Grzywa-Celińska et al., 2020.
50 S. Li et al., 2012.
51 S. Li et al., 2012.
52 Health Canada, 2021.
53 US EPA, 2015.
54 Chen et al. 2018; Duan et al. 2016; Jennings et al. 2020; Liang et al. 2019.; Li et al. 2019; Liu et al. 2018; Molemaker 2012; Partridge and Gamkhar 2012; Schikowski et al. 2014.
55 Khreis et al. 2016; Li et al. 2012; Perera 2017.
56 H Li. et al., 2015; Nieuwenhuijsen & Khreis, 2018; Xiaoxia Xue et al., 2018.
57 Chen et al. 2018.
58 Health Canada, 2021.
59 For more information about the g-Tech, please visit Navius' website: https://www.naviusresearch.com/g-Tech/
60 Environment and Climate Change Canada, 2020.
61 Environment and Climate Change Canada, 2021a.
62 Published emission and concentration trends between 1989 and 1998 for Ontario show a reasonably linear relationship between emissions and concentrations for SO_2 and NO_2 (Environmental and Health Impacts (EHI) Subgroup to the Analysis and Modelling Group, National Climate Change Process, 2000: The Environmental and Health Co-Benefits of Actions to Mitigate Climate Change).
63 The background concentrations used in this study are 1.8 micrograms per cubic metre (μg/m3) for PM2.5 (annual average), and 0.15 parts per billion by volume (ppb) for NO2 (annual average).
64 The social cost of carbon value used in this report is modelled using the latest estimate from the United States of $67/tonne in 2020, climbing at an annual rate of 1.7% to $79.60/tonne in 2030, as the authors believe this estimate more accurately reflects emerging science on the social cost of carbon. There is ongoing debate that the current Canadian value for the social cost of carbon is underestimated (Samson and Rivers, 2020).
65 For more detailed discussions of how economic values are accounted for within AQBAT, please reference the AQBAT User Guide Version 3 (Judek et al., 2019).
66 These endpoints were selected for this analysis in accordance with the related health endpoints detailed in the AQBAT user manual to avoid representing overlapping endpoints. For greater discussion of overlapping vs related health endpoints, please see AQBAT User Guide (Judek et al., 2019).
67 Details are specified in Appendix 4
68 Government of Canada, N. R.C., 2020a.
69 Reşitoğlu et al., 2015.
70 Environment and Climate Change Canada, 2021b.
71 A description of the parameters for the indicators used in this analysis is provided in Appendix 4.
72 Government of Canada, N. R. C., 2020b
73 Government of Canada, N. R. C., 2020c.
74 According to Health Canada, wood burning can produce up to 25% of airborne particulate matter, in communities where wood heating is commonplace. Other pollutants produced during wood burning include volatile organic compounds, carbon monoxide and black carbon. However, these were out of scope for this analysis (Health Canada, 2012).
75 Government of Canada, N. R. C., 2020d.
76 Bulowski, 2021.
77 Gaede et al. 2021.
78 Senate of Canada, 2018.
79 Government of Canada, 2018
80 Environment and Climate Change Canada, 2021c.
81 Government of Canada, 2020.
82 Mellross, 2020.
83 Government of Canada, 2020.
84 CBC News, 2018.
85 Government of Canada, 2020.
86 The health impacts of climate change are not quantitatively included in the partial cost-benefit analysis within this report, but are expected to be substantial. A recent report from the Canadian Institute for Climate Choices identified that quantifiable health costs alone may be in the hundreds of billions by the end of this century (Canadian Institute for Climate Choices, 2021).
87 Canadian Geographic, n.d.
88 Gouvernement du Québec, 2018.
89 Government of Canada, 2020.
90 Government of Canada, 2020.
91 Government of Canada, 2020.
92 Government of Canada, C. E. R., 2020.
93 ClimateActionwr, 2021.
94 Ibid.

95 Ministry of the Environment and Climate Change, 2016.

96 Both the 2003 On-Road Vehicle and Engine Emission Regulations, and the 2012 Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity Regulation include regulatory impact assessments which also considered air quality improvement (Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations, 2012; Regulations Amending the On-Road Vehicle and Engine Emission Regulations and Other Regulations, 2015).

97 While critical, a cost-benefit analysis shows only one part of the overall picture. Importantly, a cost benefit analysis does not consider equity concerns regarding distribution of costs and benefits,

98 Macklem, 2020.

99 Pembina, 2020.

100 Torrie et al., 2020.

101 Hetzner, 2020; Pembina, 2020; Torrie et al., 2020.

102 Linn., 2020.

103 Torrie et al., 2020.

104 Ibid.

105 Ibid.

106 Environment and Climate Change Canada, 2020.

107 Torrie et al., 2020.

108 Edger et al. 2020.

109 Green building Coalition, 2020.

110 Edger et al. 2020; Pembina, 2020; Torrie et al., 2020.

111 Pembina, 2020; Torrie et al., 2020.

112 Torrie et al., 2020.

113 Lockhart, 2020.

114 Edger et al. 2020.

115 Arregui et al., 2020.

116 Arregui et al., 2020; Edger et al. 2020; Torrie et al., 2020.

117 All population data taken from 2016 Metropolitan census.

118 Calgary Economic Development, 2020

119 Conference Board of Canada, 2021

120 Government of Ontario, 2021

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