THE BENEFITS OF CLEANER AIR:

UNPACKING THE PROCESS FOR ESTIMATES OF HEALTH CO-BENEFITS OF LOW-CARBON INFRASTRUCTURE THROUGH REDUCED AIR POLLUTION

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Smart Prosperity Institute

About Smart Prosperity Institute

Smart Prosperity Institute is a national research network and policy think tank based at the University of Ottawa. We deliver world-class research and work with public and private partners – all to advance practical policies and market solutions for a stronger, cleaner economy.
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EXECUTIVE SUMMARY

Canada's transition to net-zero emissions will lead to wide structural and economic changes. Governments will be responsible for building and supporting a broad range of low-carbon infrastructure projects. This offers the rare opportunity for governments of all sizes to advance clean growth and climate initiatives that can offer multiple benefits: reduction of greenhouse gas emissions, creation of jobs, and support healthier communities. Expanding accessibility to all levels of government of the necessary tools to undertake analyses about the impacts, and benefits, of projects for their communities is crucial to ensure all stakeholders can advocate for projects and priorities that benefit their citizens.

One area where greater work is needed to help Canadian stakeholders identify the benefits of a net-zero transition for their communities is in creating accessible approaches to identify the health benefits arising from reductions in air pollution emitted from fossil fuel combustion. It is a complicated task to recognize the potential health benefits associated with different projects in order to incorporate these considerations into decision-making. This report is an initial effort to unpack complex, and oft-times difficult to understand, authoritative processes and methodologies to assess some of the health co-benefits emerging from improvements in air quality that can result from certain types of low-carbon infrastructure projects developed in support of climate action and clean growth initiatives.

This report outlines an authoritative methodology relevant for evaluating the human health co-benefits associated with air quality changes. The methodologies outlined in this work are relevant to projects that reduce fossil fuel energy consumption and greenhouse gas emissions within Canada's buildings and electricity subsectors by a meaningful amount below traditional alternative practices, assets or technologies. Examples of projects include energy efficiency improvements for commercial and residential buildings, and deploying renewable electricity generation technologies. This report draws inspiration from the United States Environmental Protection Agency (2018) guidance document to estimate the health benefits originating from energy efficiency and renewable energy projects. However, this report provides an interpretation of how this process would be applicable to evaluating health co-benefits emerging from the adoption of low-carbon infrastructure projects in a Canadian context.

Overview of the four step approach to evaluating health benefits from reductions in air pollution as a result of low-carbon infrastructure

Step 1: Develop emissions baselines and inventories for greenhouse gases (GHG) and air pollutants	Step 2: Identify the low-carbon infrastructure project and quantify expected emissions reductions	Step 3: Estimate the air quality changes that result from emissions reductions	Step 4: Estimate the health benefits that result from changes in air quality
Decide the boundaries of an emissions inventory, and when a baseline inventory should begin. Develop an emissions inventory that identifies community emissions of greenhouse gas emissions and air pollutants. Identify the characteristics of the emissions baseline, and forecast out to a certain year to develop an emissions forecast.	Determine appropriate technique to quantify emissions reductions Estimate total emissions reductions associated with a project Compare overall emissions with both a business-as-usual (BAU) and project scenario.	Identify which pollutants are in scope for this analysis Choose the appropriate method for scenario modelling Forecast and compare the BAU and project scenarios	Estimate changes in health outcomes/endpoints emerging from improvements in air quality Assign an economic/monetary value to those outcomes

This report offers stakeholders an overview of authoritative procedures, and compiles credible tools, to undertake an analysis of the health benefits resulting from changes in air pollution. It unpacks these procedures in subsequent steps and substeps in order to clarify the process of air quality modelling and health impact estimations.

Exploratory research indicates there are no credible tools for undertaking Canadian analyses that are simple enough, for interested stakeholders without significant experience or expertise, to use in air quality or health benefits modelling. For this reason, this report fills an important gap to clarify as much as possible the necessary steps involved in a preliminary assessment of the potential health benefits emerging from projects. It can be used as a referential tool for future analyses by facilitating the identification of useful resources that can be used in the evaluation of air quality changes and health benefits.

Moving forward, Canadian governments should prioritize the development of simplified and accessible tools to assess changes in air quality, and health impacts, emerging as a result of climate and clean growth initiatives. This would ensure governments are able to identify and advocate for projects and priorities that allow them to capture a wider range of benefits in a net-zero transition.

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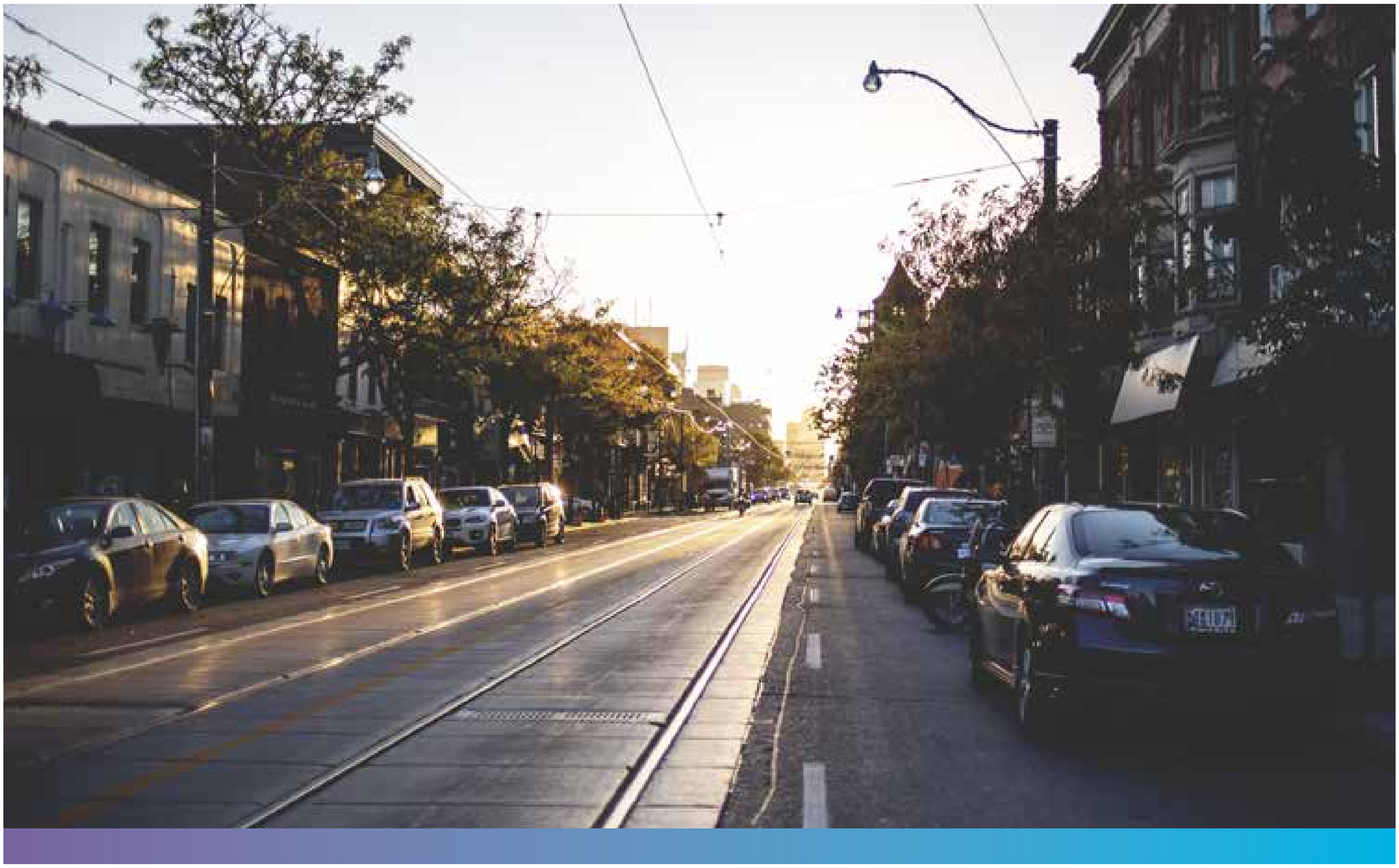
LIST OF ABBREVIATIONS

AEF	Average Emission Factor
AQBAT	Air Quality Benefits Assessment Tool
AQUI	Air Quality Health Index
AURAMS	A United Regional Air-Quality Modeling System
AVERT	Avoided Emissions and generation Tool
BAU	Business-as-Usual
BEI/MEI	Baseline Emissions Inventory/Monitoring Emissions Inventory
B-kWh	Benefits-per-Kilowatt/hour
BPT	Benefit-per-Tonne
CAAQS	Canadian Ambient Air Quality Standards
CAC	Criteria Air Contaminant
CCME	Canadian Council of Ministers of the Environment
CH_4	Methane
CMAQ	Community Multiscale Air Quality Modelling System
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
CRF	Concentration-Response Function
DF_6	Sulfur Hexaflouride
ECCC	Environment and Climate Change Canada
eGRID	Emissions & Generation Resource ntegrated Database
EPA	Environmental Protection Agency
GEM-MACH	Global Environmental Multi-Scale – Modelling Air quality and CHemistry
GHG	Greenhouse Gas
GPC	GHG Protocol for Cities
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HIA	Health Impact Assessment
ICAP	[Ontario Medical Association's] Illness Cost of Pollution Model
IEAP	International Local Government GHG Emissions Analysis Protocol
IPCC	Intergovernmental Panel on Climate Change
ISDCG	International Standard for Determining Greenhouse Gas Emissions for Cities
MEF	Marginal Emissions Factor
NF_3	Nitrogen Triflouride
N_{O2}	Nitrogen Dioxide
N_2O	Nitrous Oxide
O_3	Ozone
PFC	Perfluorocarbon
$PM_{2.5}$ & PM_{10}	Particulate Matter 2.5 & Particulate Matter 10
RSM	Response Surface Modelling
SMOKE	Sparse Matrix Operator Kernel Emissions
S-R Matrix	Source-Receptor Matrix
UNFCCC	United Nations Framework Convention on Climate Change



INTRODUCTION

Canada's transition to net-zero emissions will lead to wide structural and economic changes. This shift towards lower-carbon energy systems, more energy-efficient buildings, and zero-emitting transportation systems will require between $90 - $166 billion in total investment to meet Canada's 2030 objective, according to the Institute for Sustainable Finance[1]. The decisions around which projects will get implemented will include stakeholders and actors from across Canadian society, with all levels of government engaged in advancing climate action and clean growth initiatives.

Climate action and clean growth measures are accompanied by a host of oft-cited potential benefits to communities, including job creation, cost savings for households, and improvements to human health to name only a few[2]. The first step towards capturing these benefits is to identify the potential associated with taking action by evaluating the full suite of direct and indirect costs and benefits that are associated with the implementation of projects in their communities. Not all levels of government have the resources to undertake these assessments for the wide range of low-carbon infrastructure projects that may be advanced to support climate action and clean growth objectives. Low-carbon infrastructure projects are defined here as being any project that reduces fossil fuel energy consumption and greenhouse gas (GHG) emissions within Canada's buildings, transportation and electricity subsectors, although the process outlined in this report was designed to quantify the air quality and health benefits of energy efficiency measures in homes and buildings, and deploying renewable energy projects. Ensuring

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stakeholders working, and advocating for action, across all levels of government possess the tools needed to assess the impacts of infrastructure projects on their communities is an essential step in helping communities champion or advocate for initiatives that best serve their needs.

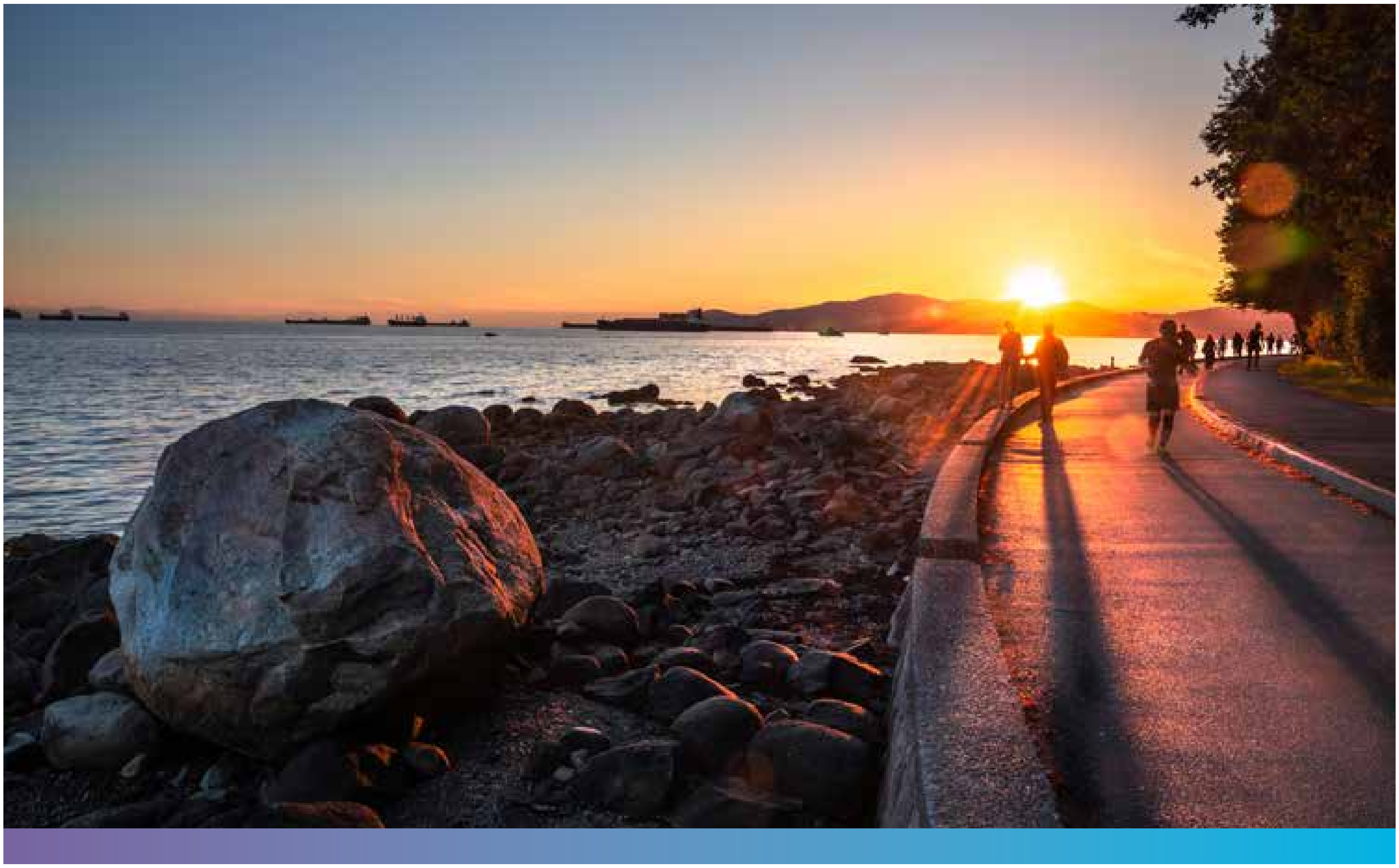
One key consideration for low-carbon infrastructure projects is their impacts on human and environmental health. Policymakers and researchers treat positive changes to air quality and improvements in human and environmental health as **co-benefits** that are associated with the implementation of low-carbon infrastructure and climate mitigation projects whose primary aim is to support economic growth or environmental objectives[3]. An assessment conducted in the US identified that human health benefits were responsible for 50-60% of monetized benefits from clean air regulations[4]. This suggests that the health benefits of low-carbon infrastructure can be substantial and are important to account for.

Assessing the full suite of health co-benefits that accompany a project is typically done through a Health Impact Assessment (HIA), which describes the health impacts of a proposed or existing project, policy or program on the population of a community[5]. Although they vary in scope, HIAs use a range of methods and processes to evaluate the potential health impacts a project has on a population. These assessments can go beyond environmental health to include considerations of impacts on physical, mental, and social well-being. Understanding the health benefits offered by a project requires undertaking a robust HIA at the community-level, a necessary step in conducting an environmental impact assessment in Canada.

HIAs are a set of complex procedures, methods, and tools that provide a credible picture of the full suite of health benefits offered by a project. A fulsome HIA is a time and resource intensive activity. In some cases, lack of accessible tools makes the assessment of specific health impacts difficult to conduct. Assessing the health benefits that come from reductions in air pollution is an illustrative example. In Canada, while a number of sophisticated models exist for estimating air quality changes, and some other models exist to estimate the health benefits emerging from reducing air pollution, simplified techniques for these types of estimations and assessments are usually not accessible and easy-to-use for stakeholders without experience in air quality modelling[6]. The lack of accessibility poses a technical and feasibility barrier for integrating these impacts into an HIA, and for comparing project benefits before a formal decision is made.

Air quality modelling is complex and technical, and so is any estimation of the health benefits associated with reducing air pollution. Although it is not possible to overcome the inherent complexity of modelling atmospheric dynamics and changes, it is possible, to a certain extent, to develop simplified tools or use simplified techniques to evaluate changes in air quality and health impacts in a manner that makes undertaking an analysis less time and resource intensive. There have been efforts to develop these more simplified techniques and accessible tools, but these still require a significant level of expertise to produce rigorous and credible health benefit estimates.

This report was developed, in part, as an effort to unpack the complex process involved in estimating the health co-benefits emerging from improvement in air quality associated with low-carbon infrastructure projects. Its objective is to help stakeholders identify credible and simplified methodologies to assess the health benefits associated with reductions in air pollution. Although these methodologies still require a certain level of expertise, this research identifies available tools to assist stakeholders in conducting their assessments in Canada, and outlines a number of alternative methodologies used elsewhere that could be adopted and adapted to the Canadian context.



WHY FOCUS ON THE HEALTH BENEFITS FROM IMPROVING AIR QUALITY?

The health impacts that emerge from low-carbon infrastructure can be wide-ranging. These impacts might be a result of the adoption or deployment of a project, or be experienced as a result of a projects impacts on determinants of health such as the physical environment, community and social factors, or livelihood and lifestyle factors[7]. Depending on the geographic scale of impacts, impacts may also vary across regions as a result of proximity. Depending on the time horizon or geographic scale selected, the health impacts can include:

- Reduction in risk of adverse health outcomes (e.g., acute respiratory symptoms, asthma, cardiac emergency room visits, child acute bronchitis, and so on) and premature mortality;
- Reduction in risk of diseases associated with physical inactivity;
- Improvements in mental health and well-being;
- Improvements in overall levels of equity and inclusion within a community.

This report focuses on tools and methodologies used for the assessment of human health benefits associated with air quality changes due to the implementation of low-carbon infrastructure. It offers Canadian stakeholders a centralized, though non-exhaustive, list of resources and available simplified methodologies to both estimate changes in air quality and the

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health benefits brought by the reduction of air pollution. These estimations, even with the use of simplified tools, still require significant resources and expertise, many times inaccessible to local governments. This report can be used as a referential document and a tool in itself that unpacks the complex process involved in evaluating the health benefits that result from improvements in air quality brought on by projects. This is an identified gap for municipal policymakers outside of larger urban/suburban centres and metropolitan areas.

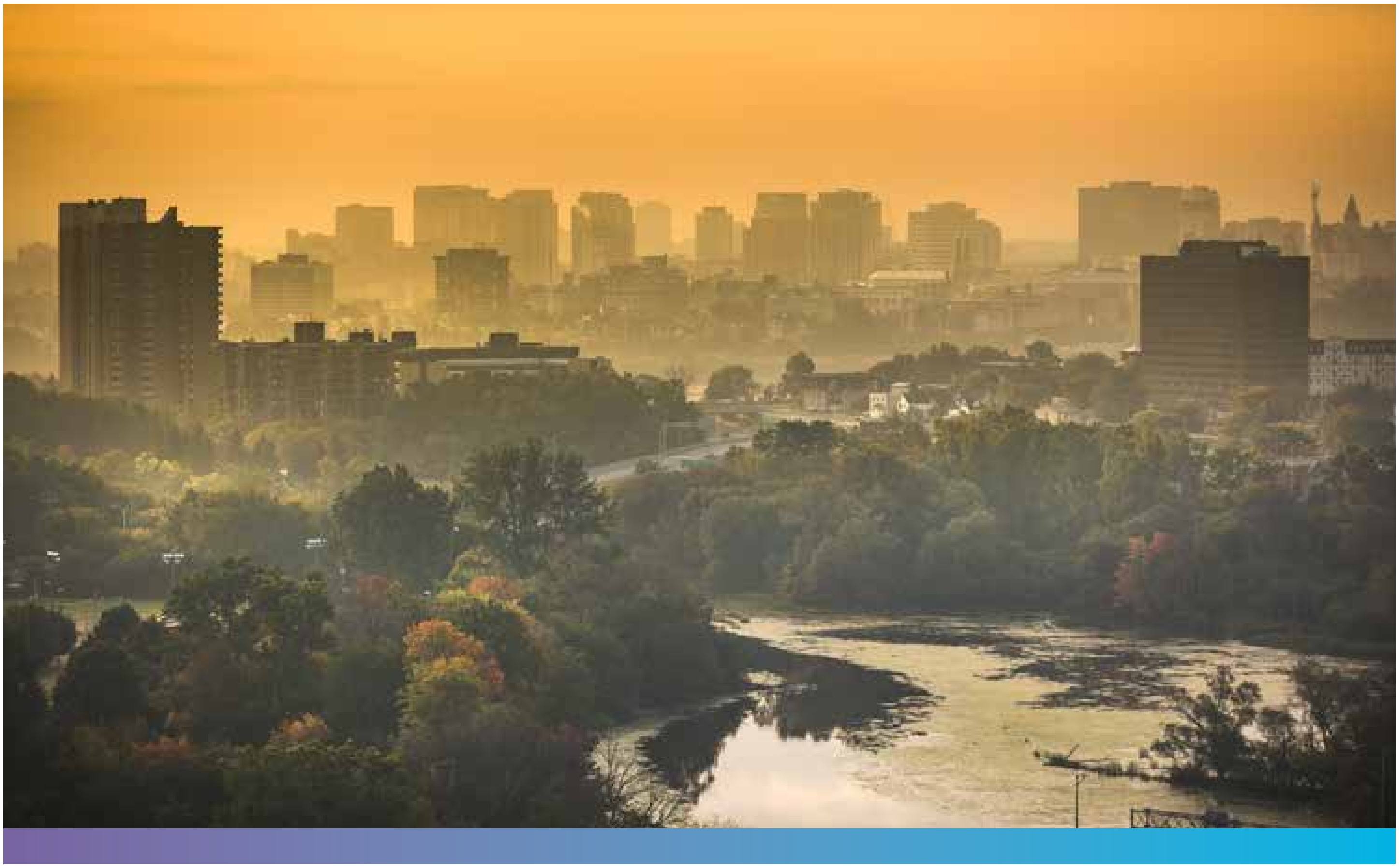
Federal, provincial, and larger municipal governments may have access to sophisticated air quality models and experts capable of using them. However, smaller governments and stakeholders often do not have access to the same levels of resources, making credible evaluations of health impacts from infrastructure projects difficult. In the United States, numerous simplified air quality models and tools exist to facilitate the assessment of the greenhouse gas (GHG) emissions and air pollution impacts of projects[8]. Despite the fact that these simplified tools still require a significant level of expertise, Canadian stakeholders face an even greater challenge; these simplified alternatives are not easily transferable to, or they are outright unavailable in, the Canadian context.

The report is thus useful for stakeholders seeking to better understand the steps involved in assessing the health benefits associated with air quality changes. Breaking down this process does not independently solve this gap, due to the complexity involved in the air quality and health co-benefits modelling. The presence of technical limitations means that estimating the health co-benefits emerging from specific or individual low-carbon infrastructure at a local scale is a significant challenge, if not a likely infeasible endeavour. Addressing accessibility, in part, will require the development of simplified tools, techniques and methods for estimating health impacts, recognizing that the value of the estimates they create can serve to inform decision-makers of potential impacts, not prescriptively or authoritatively draw causal links between a specific project and a health benefit.

Negative health effects from air pollution

According to the World Health Organization, **ambient air pollution** contributes to approximately 4.2 million deaths worldwide[9]. In Canada, 15 300 deaths are attributed air pollution occuring at above-background levels annually[10], with the total economic cost of all associated mortality and morbidity outcomes valued at approximately $131.14 billion annually[11]. Previous work from Smart Prosperity has identified adverse health impacts associated with reductions in air pollution[12].

There is a large body of epidemiological evidence identifyinging that pollutants like particulate matter 2.5 & 10, ozone, nitrogen dioxide, and sulfur dioxide incur health impacts on cardiovascular, respiratory, and neurological systems[13]. Exposure to these and other air pollutants can increase risk and/or incidence/prevalence of mortality and morbidity outcomes including asthma, chronic obstructive pulmonary disease, stroke, and coronary events, and premature death. Health impacts across each of the four types of pollutants have also been identified within the gastrointestinal and reproductive systems, and for non-communicable diseases, although evidence is not always sufficient to infer a causal relationship between exposure to a given pollutant and a health outcome, or endpoint[14].



ANALYZING HEALTH IMPACTS

This report unpacks the process involved in the analysis of the health impacts of reducing air pollution on the local population within a geographic area, which includes four overarching steps. In each step of this process, references are made to a number of credible quantification and assessment methodologies. While this report does not explicitly endorse the use of one tool, technique or model over another, it does identify a suite of credible and recognized tools, models and techniques used by stakeholders in Canada and internationally from bodies such as the GHG Protocol, US Environmental Protection Agency and Health Canada. This allows stakeholders to identify the available resources and credible simplified processes that can be used in their assessment attempts, even if these tools, techniques, or methods are designed for use in other jurisdictions. This is coupled with recommendations to federal and provincial governments that these tools be developed and shared publicly to facilitate and expedite assessments of projects to be completed by stakeholders across Canada.

Air quality modelling and estimation of health benefits, as mentioned, are fundamentally complex. The report strives to provide, in plain language, an overview of the important considerations and available simplified methods stakeholders could consider when estimating the health benefits of low-carbon projects. As mentioned, the tools and approaches outlined in this report do not represent the full suite of available tools. Certain regulations may require the use of a specific tool or assessment method in an evaluation. Depending on which health impacts a community wishes to assess, this report may be insufficient to provide all important considerations and reference necessary tools to inform a broader health impact assessment.

STEP 1: DEVELOP COMMUNITY-LEVEL BASELINES OF EMISSIONS AND POLLUTANT DATA

The first step in the process of evaluating the health impacts of changes in air pollution on human health is to assess the current levels, and sources, of emissions of GHGs and air pollutants. This assessment is known as setting a **baseline,** which offers insight into community or regional emissions by calculating current sources and levels of GHGs and air pollutants within a region. Baselines can also project the **emissions levels** of a community into the future. These projections of emissions scenarios often assume no future changes or interventions will occur (aside the expected changes that are incorporated in the emissions projections) that change emissions levels moving forward (also known as a "Business-as-usual" or BAU scenario projection).

Baseline scenarios, representing both current and future emissions levels, are useful for determining the emissions impacts of low-carbon projects. They allow stakeholders to assess how changes in emissions resulting from proposed low-carbon infrastructure projects affect current and future emissions against an established BAU scenario. Typically, the baseline covers the years for which the municipality is estimating the impacts of a low-carbon project, allowing to account for changes occurring as a result of a given project.

Baseline scenarios, representing both current and future emissions levels, are useful for determining the emissions impacts of low-carbon projects.

Most communities in Canada already have established GHG emissions inventories, developed through initiatives like creating Community Energy Plans[15]. The Air Pollutant Emissions Inventory (APEI) compiles emissions of several pollutants that contribute to poor air quality. This comprehensive inventory can be used for an overview of air quality at the national, provincial, and territorial level. Should a stakeholder wish to undertake an inventory on their own account, this report provides an introductory overview of how an emissions inventory can be developed.

There are two sub-steps in developing an emissions baseline:

- Decide what should be included in an emissions inventory, and for which year(s) a baseline inventory is required.
- Develop an emissions inventory that offers a profile of community emissions for the year(s) in question, including forecasts, within the geographic boundary selected.

Decide what should be included in an emissions inventory, and when a baseline inventory should begin

Developing an emissions inventory requires decision-making around a number of factors: Which GHGs and air pollutants are in scope; what time period is being assessed; what the geographical and sectoral boundaries are; and how the inventory will account for the sources of emissions.

Which gases or air pollutants are in scope?

The first step is to decide what gases and pollutants will be in scope for developing an emissions baseline. *The Global Protocol for Community-Scale Greenhouse Gas Emission Inventory*[16], a globally-recognized framework for setting emissions inventories, stipulates that community-inventories should include emissions of the following seven greenhouse gases:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Hydroflurorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur Hexaflouride (DF_6)
- Nitrogen Triflouride (NF_3)

These seven GHGs are outlined in the International Kyoto Protocol[17], and all of these gases are calculated and reported on in Canada's National GHG Inventory. All emissions of these gases within the boundaries of concern should be accounted for. Inventories should also account for emissions occurring outside of the boundaries of concern if they occur directly as a result of activities happening within these boundaries. Usually, baseline projections focus either on GHGs or air pollutants. For a more comprehensive analysis of the health benefits associated with the implementation of low-carbon infrastructure, it is recommended to include both air pollutants and GHGs in an emissions baseline[18].

The Government of Canada has established ambient air quality standards for a number of pollutants[19]. Some pollutants, commonly called **criteria air contaminants (CACs)**, can also be emitted as a result of the combustion of fossil fuels. They include, but are not exhaustive to:

- Sulphur oxides
- Carbon monoxide
- Nitrogen oxides
- Volatile organic compounds
- Particulate matter

Other CACs, such as ozone, are formed as a result of interactions between pollutants within ambient air. It is recommended that as many air pollutants as possible be included in an emissions baseline. Having multiple air pollutants within an initial baseline allows stakeholders greater choice in selecting which pollutants are in scope of their analysis. This means an analysis of health impacts can be better targeted to the emissions profile of a specific project or region. For a broad discussion on which pollutants might be most relevant to assess when considering the health impacts and benefits of projects, stakeholders can reference Smart Prosperity's report "The Health Co-Benefits of a Clean Growth Future"[20]. Given that the influence of air pollution on health is typically estimated through changes in overall concentration of pollutants within ambient air, calculating the emissions of air pollutants within a community is only part of the process required to evaluate how air pollution impacts air quality and human health.

What is the time period being assessed?

The next step is to identify the time period that an inventory represents. Given that baselines represent emissions levels over a set time period, this step helps identify whether emissions being represented in a baseline are shown in daily, monthly or annual figures. The standard length of time for an inventory is a continuous 12-month period.

All baseline assessments begin with identifying the baseline year. This is the year against which the reductions of emissions from a low-carbon infrastructure shall be compared. Developing a baseline for future emissions also means a "future year" must be selected to project a future BAU scenario.

It is important to keep in mind that there are several factors that fluctuate and might impact the projections of a future BAU scenario and the emission inventories of a given year. The following is a non-exhaustive list of factors that impact emissions variability[21] from year to year and, thus, should be accounted for:

- Population size (expected growth or reduction)
- Expected economic growth
- Energy and electricity production
- Expected technological advancements such as improvements in personal or public transit vehicles' fuel efficiency.

What are the sectoral boundaries?

Once a time period and baseline year are identified, stakeholders must classify emissions from city activities into source categories. According to the Sparse Matrix Operator Kernel Emissions (SMOKE) modelling documentation[22], emissions inventories are divided into several source categories. Appendix 1 lists potential inventory source categories of interest, which include stationary area, non-road mobile sources, on-road mobile sources, point sources, wildfire sources, biogenic land use. If stakeholders seek to examine the impacts of low-carbon infrastructure for a specific source, the inventory needs to cover only the emissions from the source category of interest. If they want a more granular understanding, they can disaggregate emissions.

How will the inventory account for emissions?

Another parameter that stakeholders must decide is the **scope** of their emissions inventories. Determining which emissions are in scope of a baseline will vary depending on which emissions accounting method is used. There are three primary ways to categorize emissions:

- **Scope 1 emissions**: Emissions directly produced within the geographical boundaries of interest. These are production-based emissions.
- **Scope 2 emissions**: Emissions that occur from the use or consumption of products or services, such as energy, transportation, and heating, within those same geographical boundaries. These are consumption-based emissions.
- **Scope 3 emissions**: Emissions that occur as a result of activities throughout a value chain or supply chain. These emissions can be both production and consumption-based, but all occur indirectly.

Most emissions inventories account for Scope 1 and/or Scope 2 emissions. It is possible to include both production and consumption-based data in the inventory. However, stakeholders must ensure emissions are not double-counted if emissions from both production and consumption are accounted for simultaneously.

Develop an emissions inventory that offers a profile of community emissions

Once decisions have been made on how to account for emissions, an emissions inventory can be developed. There are two main methodologies to develop a baseline inventory. These two approaches are referred to as a **top-down method** and a **bottom-up method**[23].

A **top-down method** for producing an emissions inventory accounts for produced and consumed emissions in each sector. It applies an emission factor to convert estimates of energy consumption or production into estimates of emissions that provide an aggregate picture of emissions from sectors within a municipality. A top-down methodology is useful to indicate how changes in emissions will impact entire sectors or regions. However, estimates from a top-down inventory only show overall emission changes within a sector or in the municipality. They make no clear indication as to what the causes or specific sources of the emissions beyond a sector-level analysis are, which can exclude detailed evaluations of emissions sources within a sector.

On the most basic level, quantifying carbon emissions using a top-down methodology within a baseline involves a simple formula that converts the level of activity, such as energy use or fuel consumption, into emissions estimates:

$$\text{Total emission estimates} = \text{Activity data} * \text{Emission factor}$$

Activity data refers to the total consumption of a given fuel or energy source over the baseline period, and **emission factors** are coefficients used to represent the mass of emissions released as a result of each unit of an activity.

Emission factors are then multiplied by activity data to calculate the volume of emissions that form the overall baseline. The units used to calculate activity data and emission factors often differ, and it is important that they be converted to identical units during calculations of activity data (litres, kilometres, kilowatt-hours, and so on). This is essential for ensuring GHGs and air pollutants can be compared in common units, and for converting activity data into the same unit that a given emissions factor is expressed in. Energy/unit conversion guides are compiled by governments and regulatory bodies to support this process, including this set of energy conversion tables from Canada's Energy Regulator[24]. Others can be found online to support analysis.

Once activity data is in a single common unit, stakeholders need to identify which emissions factor estimates they want to use in their calculations of their baseline. If the purpose is solely inventory accounting, **average emission factors (AEF)** are the standard type of emissions factor used. AEFs measure the average mass of emissions associated with a unit of activity, making them a useful estimate for developing an emissions inventory. **Marginal emission factors (MEF)** are coefficients of changes in emissions from a proposed project, and they vary depending on which type of activity occurs and the emissions profile of a given unit. MEFs are typically used when estimating incremental changes in emissions from changes in projects or end-uses. A useful way to consider this difference is that AEFs are used to describe overall emissions within a sector, while MEFs are used to identify how a specific project impacts emissions level. As such, it is important to bear in mind that AEF and MEF serve two distinct purposes: AEF are used to provide an overall descriptive picture of mass emissions for each unit of activity, whereas MEF serve to calculate emissions changes resulting from the implementation of specific projects.

There are a number of sources available for identifying emissions factors. Appendix 2 presents a list of databases and tools that compile emission factors, from Canadian and other credible international sources.

When calculating total emissions, all seven GHGs will need to be converted into a common metric (**carbon dioxide equivalence**, or CO_{2e}). The CO_{2e} value of each gas can be calculated by multiplying the volume of each gas by its **Global Warming Potential** (GWP). GWP represents the overall impact on planetary warming a given gas will have relative to a tonne of carbon dioxide. The use of GWP estimates, a standard practice, allows stakeholders to represent the total volume of GHGs from a given sector in a single value. Generally accepted GWP estimates are developed by international organizations, and are compiled and updated regularly by groups such as the GHG Protocol[25]. Calculating air pollutant emissions within a baseline can similarly use emissions factors listed in Appendix 2.

A **bottom-up method** for compiling an emissions inventory, by contrast, collects data from the specific sources of emissions. Instead of focusing on aggregate energy use in a sector, bottom-up emissions inventories are created by collecting emissions data from each activity from the ground. This requires the collection of data on the number and type of sources of emissions and air pollutants within a municipality. Bottom-up inventories are data intensive, and because they provide more accurate estimates of emissions within the sector of interest, they allow for more sophisticated scenario modelling. Table 1 below compares the two approaches.

If stakeholders want to develop a bottom-up inventory, it is necessary to identify emissions sources from specific projects or facilities when compiling an overall baseline. While data requirements differ by the type of methodology adopted to create an inventory, data collection is an important step across all emissions inventories, and must be considered prior to the development of an inventory.

Once emission inventories are developed, stakeholders are able to forecast future emissions. This allows communities to create a BAU forecast of emissions that can then be used to assess the reduction potential of projects. Stakeholders can also use future projections to conduct air quality analysis and track the progress brought by the implementation of new infrastructure.

Appendix 3 lists a number of tools and resources that stakeholders can use to calculate, manage, project, and report emissions. For a detailed step-by-step guide to create GHG emissions inventories, for those who wish to do so, stakeholders can read this handbook by Partners for Climate Protection[26].

Table 1: Comparing a top-down and bottom-up method

	Top-down approach	Bottom-up approach
Purpose	For developing city-wide estimates of criteria air pollutants or GHGs.	For developing sector-specific inventories and calculating source emission estimates.
Strengths	Provides an overview of emissions in a municipality.	Provides a more nuanced and granular profile of emissions within a municipality.
Limitations	It lacks in-depth sectoral insight, and increases the risk of uncertainty when using averaged emission factors.	Data intensive, requiring disaggregated data which can be costly or difficult to collect.
Data	Data on city-wide production or consumption of services and products within the sector of interest, as well as data on economic activity and population levels.	Data on emissions sources for each sector of interest, activity data, and emissions monitoring data for each source.

STEP 2: INFRASTRUCTURE PROJECT AND QUANTIFY EXPECTED EMISSIONS REDUCTIONS

Step 1 in this process involves developing an emissions baseline for a community that includes both GHGs and air pollutants. This second step involves quantifying the emissions reductions potential of a given project. This section unpacks the processes involved in estimating the impacts of a project on emissions levels within the geographic boundary selected. This is calculated by examining what activity would be displaced by a given project. This change is then compared to the BAU scenario. Such comparison allows stakeholders to assess how a given project will impact overall GHG and air pollution emissions within the community.

Emissions reductions for each type of project featured in this report (energy efficiency and renewable energy projects) emerge as a result of avoided electricity generation. However, emissions reductions for projects can also occur as a result of avoided consumption of other fuels used to heat homes and buildings such as natural gas. This report focuses on calculating emissions impacts from avoided electricity generation, but a similar process can be used to calculate avoided emissions from these other energy sources. Calculating these emissions impacts can be done by multiplying the avoided electricity generation by the MEF for the electricity system used within a given region[27]:

$$\text{Total Emissions Reductions} = \text{Avoided electricity generation} * \text{Marginal Emission Factor}$$

This formula offers one approach to quantify a project's impacts on emissions. However, there are a number of factors that can be accounted for to improve the accuracy and complexity of the analysis of the emissions impacts of a given energy efficiency or renewable energy project[28]. Depending on whether stakeholders want to integrate these factors into their analysis, different approaches for quantifying emissions reductions may be more desirable. These factors, explored here based on how they could impact emissions from a range of low-carbon infrastructure projects, include:

- **Accounting for the carbon intensity of displaced energy** involves calculating the load profile of the electricity that happens to be generated and dispatched at a given point in time. This can help identify the source of the electricity that is displaced, and more accurately estimate the emissions impacts of a given energy asset. Depending on the level of complexity involved, this can also account for imports or exports of electricity onto the electricity grid from other jurisdictions.

- **Variability in an electricity asset's generation profile** can impact when electricity is generated, and how much is generated. This is a particular factor for renewable energy projects. This variability is an additional factor that contributes to the complexity of accounting for the overall carbon emissions displaced by a project. One way of accounting for daily variance is to establish a "load profile" for an energy asset that identifies the average times of day that asset generates electricity in a given region, and accounts for the emissions intensity of energy displaced. This can be compared to the daily average emissions intensity of the overall grid, and offers specific insights about what electricity generated at specific points displaces.

- **Seasonal demand and performance factors** have a strong impact on overall energy usage, and therefore influence the emissions displaced by a given project. Average energy demand rises in the winter in Canada. Accounting for how seasonal demand and performance can impact overall emissions can help offer a more accurate annual picture of total emissions displaced. Similar to accounting for daily or hourly variance, one technique to account for these measures is to define average performance by season and account for emissions displacement seasonally.

- **Use patterns** have a significant impact on overall emissions levels. The more frequently a low-carbon infrastructure asset is used, the more emissions it has the potential to displace. The use-pattern of an asset will also have impacts on emissions. In some cases, accounting for this requires accounting for variability in an asset's generation profile. In others, it may mean accounting for the fact that potential energy saved through greater energy efficiency may be reduced by increases in energy consumption that at least partially offset these savings, a phenomenon known as the rebound effect[29]. Accounting for these use patterns can help stakeholders better understand the emissions reductions potential of a project in a particular region.

- **Fuel price impacts on overall energy use** are a key variable in assessing the emissions impacts of a given solution. If energy prices (i.e., electricity or natural gas) are low, then potential increases in overall energy demand may offset emissions benefits from a given project. Depending on the structure of the electricity market in a given province, it may lower the overall usage rate of a given low-carbon infrastructure project for a period of time. Accounting for price changes through a sensitivity analysis is a useful way to ensure potential changes in energy prices are represented in an emissions reduction calculation.

There are a number of available models and techniques that integrate these characteristics directly. They often require an intermediate or advanced level of technical expertise. For low-carbon infrastructure projects that go beyond energy efficiency measures and renewable energy, many of the factors listed above will still be applicable.

This report lists and briefly describes three emissions quantification approaches[30], presented in order of increasing complexity.

- **Adopt pre-existing Marginal Emission Factor (MEF):** Similar to the process outlined in Step 1, this approach involves the multiplication of the amount of energy generation displaced from the low-carbon program (i.e., activity data) by coefficient representing the emission rate for the electric generating unit (i.e., MEF). It is useful for stakeholders wishing to identify the relative magnitude of GHG and air pollutant emissions reductions of a particular low-carbon project.

- **Proxy Plant:** This method involves choosing an electric generating unit as a proxy to represent the emissions of another unit that would have been built if not for the energy demand reductions due to the implementation of low-carbon projects. This method is only recommended if other basic approaches are not feasible, as proxy plants may skew analysis and introduce significant uncertainties in measurement and estimations.

- **Capacity Factor Analysis:** This method uses a displacement curve, a technique that models when and where electricity is generated from an asset, to more accurately estimate the emissions rate of a project and calculate its emissions reduction potential. This approach allows for the creation of a customized marginal emission factor that better reflects the operating characteristics of a specific resource. This method is useful to determine the likelihood of an electric generating unit to be displaced by the implementation of low-carbon infrastructure. It requires data on historical generation and emissions rates.

Table 2 summarizes the main requirements and characteristics of the above methods for quantifying emissions reductions across a range of low-carbon infrastructure projects. While the table largely focuses on methods for calculating the emissions impacts of energy efficiency and renewable energy projects, these techniques can be used to account for electrification across a range of end-use applications including home heating and transportation.

> ***Once the changes in emissions levels have been calculated, determining the emissions reduction expected from the implementation of low-carbon projects involves the comparison of the project scenario with the BAU scenario.***

Table 2: Characteristics and requirements of different methods to calculate emissions reductions

	Adopting Preexisting MEFs	Proxy Plant	Capacity Factor Analysis
Analytical capacity	• Calculates basic estimates of energy efficiency or renewable energy benefits	• Identifies which electric generating units are on the margin and estimate seasonal or annual avoided emissions	• Quantifies hourly emission reductions • Estimates emissions reduction during peak electricity demand
Main Assumptions	• Assumes no variability in operation of electric generating units	• Assumes no variability in operations and characteristics of electricity generating units • Only represents a single unit type that is always on the margin	• Can assume that no electricity is imported • Does not incorporate local constraints to transmission or distribution
Data requirements	• Annual or seasonal energy impacts (megawatt-hour) • Non-baseload emission rates • Bundled technology emission rates • Technology-specific emission rates	• Annual or seasonal energy impacts (megawatt-hour)	• Hourly energy impacts (megawatts and/or megawatt-hour)
Advantages	• - Simple computations • - Requires less data than Capacity Factor Analysis	• - Requires the least amount of data	• Considers generation resource characteristics
Shortcomings	• Because energy savings change over time, this approach may skew the actual emissions benefits estimates • Fail to account for potential changes from new regulations and technological improvements • Neglects power transfer between regions	• Insensitive to maintenance or outages	• Insensitive to dispatch processes • More resource intensive than proxy plant approaches
Tools	AVERT eGRID List of resources compiling MEFs can be found in Table 1*	N/A	eGRID

*It is recommended stakeholders use MEFs that are region specific where appropriate.

For additional information or further clarification on the application of these methods, it is recommended to consult specialized guides. Two options are the Environmental Protection Agency's Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy protocol[31], and the State and Local Energy Efficiency Action Network's Energy Efficiency Program Impact Evaluation Guide[32]. While both of these resources were developed in the USA, they cumulatively offer an overview of methods for GHG quantification, air quality modelling and health impact assessments that can be largely applicable in Canada. Stakeholders should select and identify the techniques and tools that offer the depth of analysis they require, while noting which factors listed above are in or out of scope to ensure they are accounting for the granularity of their emissions estimates.

Once the changes in emissions levels have been calculated, determining the emissions reduction expected from the implementation of low-carbon projects involves the comparison of the project scenario with the BAU scenario. As such, the impact of the project on the emissions is the difference between the emissions of the baseline and the emissions of the project scenario:

$$\text{Project emissions impact} = \text{Emissions of BAU scenario} - \text{Emissions of project scenario}$$

This approach involves the comparison of the emissions reduction potential of a project against the current emissions baseline and a BAU emissions projection. Once this is completed, stakeholders will have identified two scenarios: One of BAU emissions, and another scenario where a low-carbon infrastructure project is installed, which can then be used to identify how emissions reductions occurring as a result of a project impacts changes in air quality.

STEP 3: ESTIMATE THE AIR QUALITY CHANGES THAT RESULT FROM EMISSIONS REDUCTIONS WITHIN THE COMMUNITY

The implementation and use of low-carbon infrastructure can be associated with reduction of air pollution and improvements of air quality[33]. Air pollution has been causally linked to mortality and morbidity outcomes, including respiratory and cardiovascular disease, and premature mortality. This report offers an overview of how emissions impacts of a specific project are calculated (see Step 1 and 2). The third step in this process involves shifting from assessments of emissions to assessing air quality. Evaluating health impacts from air pollution is conducted through assessing how changes in emissions impact ambient air quality within a certain geographical boundary of interest.

There are important considerations for stakeholders looking to estimate changes in air quality from emissions reductions as a result of a project. This step identifies and describes, at a high level, methodologies to estimate the air quality impacts of a BAU scenario and a project scenario, with the difference between the two being used to estimate the change in air quality that occurs as a result of a given low-carbon infrastructure project.

It is outside of the scope of this report to provide an in-depth explanation of the necessary steps to conduct an air quality assessment that is aligned with regulatory requirements for air quality in Canada. The following is a review of important factors that stakeholders must be aware of when conducting any assessment of air quality.

There are three basic steps to calculate how changes in emissions impact air quality within a region:

1. Identify which pollutants are in scope for this analysis
2. Choose the appropriate method for scenario modelling
3. Forecast and compare the BAU and project scenarios

Identify which pollutants are in scope for this analysis

Project-related activities may change the air pollution concentrations in a specific location. Selecting which specific air pollutants should be modelled will depend on the emissions resulting from a specific project.

It is important to determine which pollutants will be modelled to evaluate changes in air quality. The inclusion of pollutants should mirror project-specific emissions. However, stakeholders should keep in mind that assessments of air quality are already conducted by Canadian governments using an identified set of pollutants. In Canada, the Canadian Council of Ministers of the Environment (CCME) developed the Canadian Ambient Air Quality Standards (CAAQS), which provide air quality standards against which to evaluate ambient concentrations of air pollutants. The CAAQS can be used in conjunction with the Air Quality Health Index (AQHI), a risk communication tool that provides stakeholders a summary of the most recent forecast values of air quality for many Canadian cities. The CAAQS measures air quality by examining concentrations of four pollutants:

- Ozone (O_3) at ground-level;
- Particulate matter ($PM_{2.5}$);
- Sulphur dioxide (SO_2); and,
- Nitrogen dioxide (NO_2).

Other factors to consider involve selecting the pollutants originally included within a project baseline, and if there are additional air pollutants stakeholders seek to examine. When deciding whether other **contaminants of potential concern** should be included, stakeholders can consult environmental impact or risk assessments reports, Canada's National Pollutant Release Inventory (for point sources), and Air Pollutant Emissions Inventory to identify emissions and air pollutants from project-specific activities.

Another consideration when selecting pollutants is that some pollutants are emitted directly from a source (primary pollutants) while others are formed by complex chemical reactions of **gaseous precursors** in the atmosphere (secondary pollutants). It is important to identify which primary pollutants, or gaseous precursors, are within the scope of their analysis to better understand how emissions levels will impact changes in air quality. Additionally, any assessment of changes in air quality needs to account for the chemical transformations of primary/precursor pollutants into secondary pollutants to accurately estimate changes in air quality. This is a built-in feature of most of the commonly-used air quality models referenced in this report.

Air quality assessments involve taking a number of factors into account, each of which has the potential to increase the complexity of ambient air quality modelling and reflect air quality changes at the local level. These factors include[34]:

- **Project characteristics:** Throughout its lifecycle, a project can impact emissions of air pollutants. It is possible to estimate the emissions impact of all phases of a project, from development and implementation to decommission and abandonment. Defining the timespan used to evaluate its contribution to air pollution will vary depending on whether the full project lifecycle is assessed. Additionally, the use-pattern of a given project will affect its contributions. A given project's contribution to overall air quality may therefore vary, depending on the measures used to assess changes in air quality.

- **Geographical boundaries:** Spatial scope is an important factor in any air quality model or measurement, as the definition of the geographic boundaries of the analysis will vary depending on the region of interest. The air quality impact of a certain project may extend over large or smaller areas, depending on which air pollutants are emitted. Additionally, air pollution travels and some pollutants are transformed into secondary pollutants, making the setting of geographic boundaries important to scope an analysis. It is important to note that the distance to the souce of emissions is an important factor to consider, since it impacts dispersion of pollutants.

- **Meteorological and topographical conditions:** Similar to geographic boundaries, the topographic shape of the landscape and weather patterns influence how pollutants disperse across the landscape, potential transformations into secondary pollutants, and where they eventually settle (known as "sedimentation").

- **The exposure time frame of a given pollutant:** The duration of exposure to air pollutants, usually classified as acute (short-term) or chronic (long-term) exposures must be carefully considered. Although the relationships between air pollution exposure and health outcomes are complex, and exposure is only one of the many factors that may contribute to the onset of diseases, acute exposure to some pollutants may result in human health effects, while for other pollutants (or combination of pollutants), health effects may occur after chronic exposures. Some other pollutants, such as ozone and particulate matter, are non-threshold substances, meaning that impacts to human health can occur at any level of exposure.

Given the breadth of considerations that can be accounted for in assessments, selecting an air quality modelling tool that reflects these considerations, as well as responds to data and resource constraints, is an important step once the pollutants under evaluation are identified.

Choose the appropriate method for scenario modelling

The project scenario describes the anticipated emissions levels in a scenario where a project will be fully implemented. The development of a project scenario thus allows to estimate the contribution of a specific project to the concentration of pollutants in ambient air, relative to the BAU scenario. The air quality impact of a particular low-carbon infrastructure is assumed to be the difference of pollution concentrations between the baseline and the project scenario.

Reduced-form screening methods use a set of simplified tools and strategies that take the output of complex models and simplifies their assumptions, which outlines a series of relationships between pollutants in a given region and offer insight into subsequent air quality changes based on these simplifying assumptions.

In BAU scenarios, concentrations of air pollutants within ambient air are usually accounted for and reported in concentrations (micrograms per cubic metre ($\mu g/m^3$) or parts per billion (ppb)). That is because air concentration levels of pollutants are generally a key measure of air quality.

The following are some of the available types of air quality models for Canadian stakeholders. Each provides varying levels of detail in their representation of air quality changes occurring within each emissions scenario:

- **Dispersion models:** These models are ideal for predicting the dispersion of air emissions and its impact on concentration of ambient air pollutants. Although appropriate for modeling pollutants emitted directly from source, dispersion models lack sophistication to analyze atmospheric chemical reactions producing secondary pollutants[35].
- **Photochemical models:** These models involve complex simulations that are capable of capturing both ground-level concentrations of primary pollutants and atmospheric reactions that produce secondary pollutants such as ozone and secondary $PM_{2.5}$. Photochemical models depict the ways in which air pollution forms, accumulates and dissipates by characterizing physical and chemical processes in the atmosphere[36]. Additional information about different types of photochemical models can be found here.
- **Receptor models:** These models provide estimates of source-specific contributions to air pollutant concentrations. There are two basic types of receptor models: 1) Chemical Mass Balance, used mostly for quantifying the source contribution of primary emissions[37] when detailed profile of the source is available[38], and; 2) Positive Matrix Factorization[39], which estimates the contribution of particular sources to air pollution without prior information on sources[40]. Additional information on these different types of receptor models can be found here.

These types of air quality models require varying levels of data to account for different factors impacting air quality. It is important to determine data and resource availability when choosing a model.

For stakeholders interested in using an above model to conduct an analysis of air quality changes in Canada, the Government of Canada has developed a guide that provides additional considerations on scenario modelling, and stakeholders are invited to consult Health Canada's Guidance for Evaluating Human Health Impacts in Environmental Assessment: Air Quality. One tool available for Canadian policymakers is the Community Multiscale Air Quality (CMAQ) Modeling System developed by the US Environmental Protection Agency (EPA), a type of photochemical model that is quite resource intensive, but that provides a comprehensive representation of atmospheric processes. Environment and Climate Change Canada (ECCC) has also developed the Unified Regional Air-Quality Modeling System (AURAMS)[41,]. Like EPA's CMAQ, the AURAMS provides estimates and projections of concentrations of primary and secondary air pollutants, allowing an indication of how emissions reductions impact air quality[42]. Currently, the ECCC uses an advanced chemical transport and meteorological model known as Global Environmental Multi-scale - Modelling Air quality and CHemistry (GEM-MACH)[43] for all of its air quality modelling.

Of the four models commonly used to conduct assessments across Canada that are outlined above, CMAQ is publicly available for download and use by any party. Data from Canada's National Air Pollutant Survey has been used to evaluate changes in air quality in the past[44]. AURAMS cannot be downloaded for direct use by stakeholders for use in Canada, but stakeholders can contact Environment and Climate Change Canada to request support in conducting an evaluation. GEM-MACH is not publicly available.

Simplified alternatives used in other jurisdictions

Modeling air quality changes from emissions reductions is a complex task that requires a host of considerations such as the ones outlined above. The US EPA has developed alternatives, known as **reduced-form screening** methods, that expedite the evaluation of air quality impacts of a specific project, which can be especially useful when time and resources availability is limited**.** Reduced-form screening methods use a set of simplified tools and strategies that take the output of complex models and simplifies their assumptions, which outlines a series of relationships between pollutants in a given region and offers insight into subsequent air quality changes based on these simplifying assumptions. The following are a non-exhaustive list of types of commonly-used reduced-form screening tools and techniques:

- **Source-Receptor (S-R) Matrix**: This technique outlines a series of source-receptor relationships. Source-receptor relationships link changes in emissions of a given pollutant to changes in air quality concentration levels, translating emissions changes into changes in air pollutant concentrations. This reduced-form technique is commonly used when undertaking a more detailed analysis becomes too resource-intensive. One commonly-used S-R Matrix can be found in the EPA's Co-Benefits Risk Assessment Health Impacts (COBRA) Model, which simulates the relationship between emissions and ambient air pollutants.
- **Response Surface Modeling (RSM)**: Also known as air quality meta-modelling, this technique simulates the relationship between a certain pollutant and emission reductions for a given time period[45]. RSM techniques simplify the estimation of how a predicted change in emissions impact overall air quality within a region. They represent changes in air pollution as multipliers, where a change of X% of Pollutant 1 leads to a change of Y% of Pollutant 2. For example, if 10% reduction of a precursor pollutant (emissions) leads to 5% reduction of the concentration of a particular pollutant, then 20% reduction of the same precursor pollutant is expected to reduce the ambient concentration of the other pollutant by 10%.

There are a number of reduced-form screening tools and techniques that also examine health impacts, a non-exhaustive list of which are included in Appendix 4. Although each of these techniques is credible and commonly-used globally, there have not been reduced-form air quality models developed in Canada that are comparable to the US tools identified above. Each tool outlined above is accompanied by applications guides and training tools accessible on the US EPA's website.

STEP 4: IDENTIFY HEALTH BENEFITS THAT RESULT FROM CHANGES IN AIR QUALITY

Once changes in air quality resulting from a project have been established, the final step in this process is to identify the health impacts that might occur as a result of this change, and quantify the economic value of the health co-benefits associated with emissions reductions.

How are health benefits calculated?

There are a number of ways to consider the health impacts that emerge from reducing air pollution. Health outcomes, or endpoints, are commonly represented as acute effects (effects that occur rapidly after exposure to a pollutant, and are short-term) or chronic effects (impacts that develop slowly over time, and are long-term). Each change in health endpoints is calculated using a **concentration-response function**[46]. A concentration-response function is a statistically derived estimate that quantifies. The impact of a pollutant on a specific health endpoint[47]. It represents the relationship between the exposure to given pollutant and the associated adverse health impacts to a given population brought on by this exposure[48]. The value of this function provides an indication of how exposure to ambient air pollution can impact the health of a particular group of people.

Once changes in health endpoints are calculated, a monetary or economic value is assigned to each change. These values are calculated based on epidemiological studies that identify the economic costs associated with an illness or negative health endpoint, and the social values people place on non-monetary goods such as reducing the risk of pain, suffering and mortality, and lost productivity[49]. Once calculated, values are assigned to outcomes like respiratory and cardiac emergency room visits, respiratory mortality, acute respiratory symptom days, asthma symptom days, minor restricted activity days, respiratory hospital admissions, avoided premature deaths, and so on[50].

A commonly-used approach for quantifying the impact of exposure to air pollutants on human health in the US, European Union and Canada is the **damage-function** method[51]. The full use of the damage function method involves conducting an analysis similar to the sequence of steps outlined in this report:

1. Emissions of greenhouse gases and air pollutants are quantified in a specific area;

2. These values are inputted into an air pollution model to estimate concentrations of air pollutants in a given region;

3. Concentration-response functions are applied to predict how changes in air pollution will affect health endpoints. These could include changes in mortality, illnesses, absences from work and school, or days where restricted activity is advisable. Concentration response functions are applied to population estimates, baseline endpoint rates and the geographic area in the scope for the assessment to evaluate how different groups will be affected;

4. Monetary or economic values are assigned to each of these impacts to estimate the overall cost of action or inaction from each.

Use of the damage function method is relevant when stakeholders are interested in assessing the complex relationship between changes in air quality and health with more specificity than basic methods. The calculations of health benefits involve complex modelling that require the use of specialized software or computers. These models use a sophisticated damage function approach to quantify the total benefits to human health, resulting from a reduction in adverse health impacts, occurring from a change in emissions and subsequent improvement in air quality. Each health endpoint uses a unique concentration-response function to identify how changes in a particular pollutant will impact a population. Damage functions take the following four factors into account:

- **Pollution concentration changes** measure the change in concentrations of air pollutants in ambient air that result from a reduction in emissions of greenhouse gases/air pollutants.

- **Concentration-response functions**.

- **Exposed population** is the number of people affected by an air pollutant in a given region. Since air pollution impacts different members of a population in a range of ways, stakeholders looking to better understand the impacts of changes to air quality in their community can measure impacts by a number of criteria. While it is possible to assess impacts by age ranges, gender, minority communities and income levels, any analysis on these characteristics requires that data for each be available, and that analyses of these factors be available as a feature within a given model.

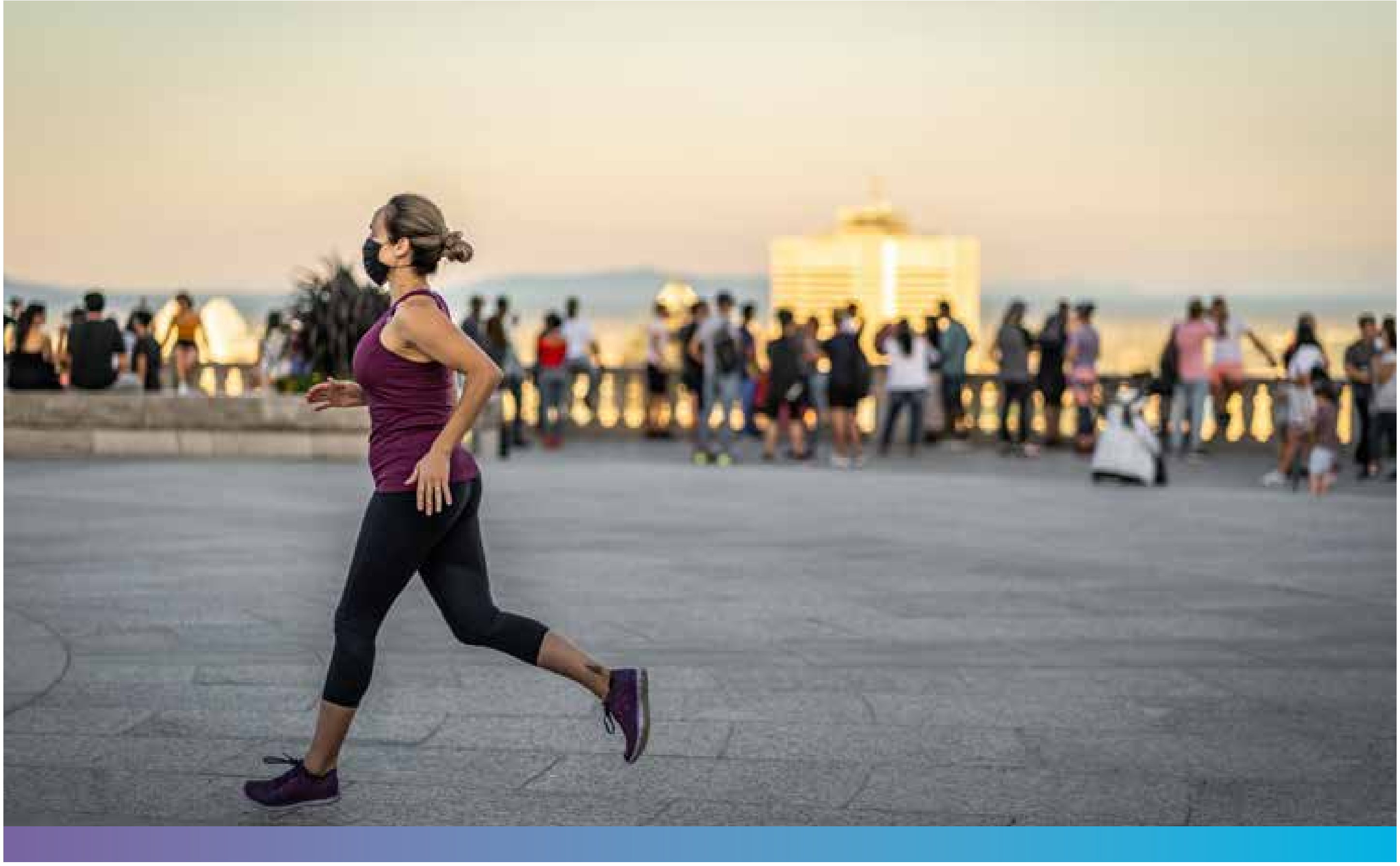
- **Baseline health outcomes** is an estimate of the average number of people who experience an adverse health impact in a given population over a set period of time. It is included to assess how changes in this baseline rate are impacted by changes in air pollutants in ambient air from a given project. Baseline health outcomes should also take ailments that are prevalent within a subset of the population into account, such as asthma, since they will affect only a percentage of the overall population.

These four factors are then computed to develop estimates of health effects on a range of health endpoints. Once these estimates are calculated, an economic value is assigned to each health endpoint to estimate an overall monetary value to the health impacts emerging as a result of changes in air quality. This facilitates the communication of the overall monetary value of a set of health co-benefits that emerge from reductions in air pollution as a result of projects.

For stakeholders interested in conducting an analysis in Canada, a list of prominent tools used internationally to estimate health benefits from low-carbon infrastructure is available in Appendix 4, including the US EPA's BenMAP program and the World Health Organization's AirQ Model. One tool frequently used in Canada to conduct assessment of the health impacts of changes in air quality is the **Air Quality Benefits Assessment Tool (AQBAT)** developed by Health Canada. Users can contact Health Canada to receive a copy of the model, which can be applied at a regional and national level, to conduct assessments of how changes in levels of air pollution, calculated in Step 3, will affect a range of mortality and morbidity outcomes.

Other health assessment models have also been used in Canada in the past, including the Ontario Medical Association's Illness Cost of Air Pollution Model (ICAP), and the EPA's BENMap program. BENMap has a Canadian data set that includes population data, baseline death rates and air quality levels, and geographical grids available for download that users can use to conduct analysis.

AQBAT and BENMap are both publicly available for use for assessments (the former is a downloadable Excel tool and the latter is an open-source online tool). Using each requires a level of familiarity with modelling softwares that evaluate air quality changes and health impacts. These models are accompanied by user guides to help stakeholders walk through the modelling process, and better understand the input and output requirements of each model.



SIMPLIFIED ALTERNATIVES TO IN-DEPTH ASSESSMENTS

As detailed in this report, undertaking an analysis of the health impacts arising from reductions in air pollution due to low-carbon infrastructure projects is a complex, technical exercise that is not accessible to stakeholders without significant experience in air quality or health effects modelling. Some of the more complex models for undertaking only one step of this analysis, such as using a photochemical model like CMAQ to evaluate changes in air quality, are highly computationally intensive, requiring a significant level of expertise, time, and computing power to run. Exploratory research and expert consultation conducted for this report identifies that the majority of available air quality and health impact assessment models, even the simplified ones, involve a certain degree of sophistication, requiring high levels of expertise, and access to complex computational resources.

This emphasizes a need for simplified tools, techniques or methods to make analyses more accessible, while recognizing that using even a simplified process will be a multi-step, technical process to estimate the health benefits from emissions reductions.

Some jurisdictions have developed simplified strategies to calculate the health benefits from changes in air quality, such as the reduced-form methods or techniques developed by the US EPA. These simpler methods offer broad insights into how changes in air pollution influence health impacts on averaged terms.

One technique used is to develop **benefit-per-tonne** (BPT) estimates or **benefit-per-kilowatt/hour** (B-kWh) estimates. BPT/B-kWh estimates are quantitative approximations of the overall health benefit associated with reducing a tonne of a given air pollutant from a particular source, or from reducing a kilowatt-hour of energy from a particular source in a particular region[52]. B-kWh estimates do not measure health effects from changes in air pollution, but make projections based on changes in the usage of a given fuel. BPT/B-kWh estimates assign a monetary value to reductions in emissions from a particular source, sector, or generally within a region. These estimates are generally calculated by running numerous potential emissions scenarios through either reduced-form or advanced air quality models, quantifying the human health burdens that result from the air pollution, and dividing the sum of total health impacts by the mass of emissions changes, although advanced photochemical models can use alternative approaches. The output figure from this analysis represents an estimate of the total health benefit associated with one tonne of reduction from a particular pollutant. BPT/B-kWh values are therefore useful proxies that can offer quick approximations into how changes in emissions from a given source in a particular region can benefit human health. Applying a BPT/B-kWh estimate to evaluate health benefits requires stakeholders to assess the emissions change emerging from a given project, similar to the process outlined in Step 1 and Step 2, and multiply that change by a compatible BPT/B-kWh estimate to get a estimation of the value of the health benefits that emerge from this change in emissions.

BPT/B-kWh estimates are useful, as they are simple to use and can offer quick insights. However, the following should be kept in mind:

- BPT/B-kWh estimates are pollutant specific, and are often sector and region-specific. There are limited available BPT estimates compiled in Canada. It is not advisable that BPT estimates from other regions be used to measure health benefits in another area.

- Estimates are limited in their ability to account for how health impacts affect different segments of the population. This can limit the overall value of an analysis, since the impacts of air pollution on a given population vary by community or region. Air pollutants can affect groups like seniors, children and young adults differently, which influences the health impacts from changes in air quality.

- BPT/B-kWh values cannot be modified. This means that communities cannot modify the assumptions that went into calculating these estimates including years of population exposure, different values for health or human life, or any changes in air quality models.

BPT/B-kWh estimates are quantitative approximations of the overall health benefit associated with reducing a tonne of a given air pollutant from a particular source, or from reducing a kilowatthour of energy from a particular source in a particular region.

With all limitations and strengths of reduced form methods for estimating and monetizing health benefits from air quality changes, it is important to bear in mind that, without context-specific BPT/B-kWh estimates, stakeholders cannot use these values without a significant risk of bias and decreased accuracy. However, they represent a promising approach to simplifying analyses of health benefits from emissions changes, and developing Canadian estimates would greatly improve accessibility of analyses for Canadian stakeholders.

RECOMMENDATIONS
FOR IMPROVING THE ACCESSIBILITY OF HEALTHY AIR ANALYSIS FOR CANADIAN POLICYMAKERS

This report set out to identify an overarching process for conducting an evaluation of the health benefits emerging from improvements in air quality. Conducting this assessment is ultimately a complex, technical exercise that is out of reach for most stakeholders, except for those with significant experience evaluating air quality changes or health effects. Some of the tools and approaches identified in this report, including a number of reduced-form tools, models and techniques, can support greater accessibility within analyses. However, these tools are largely not well-suited for analysis in Canada due to the fact that they are customized for use in other regions.

This report recommends that Canadian governments and experts develop Canada-specific reduced-form tools for stakeholder use in assessments of changes in air quality and health effects.

A few tools outlined in Step 3 of this report, including the Source-Receptor Matrix technique and Resource Surface Models (RSM), are globally-recognized techniques used in other jurisdictions to assist stakeholder analyses of air quality. Developing a larger number of reduced-form tools, techniques or methods for use by Canadian stakeholders to undertake both air quality and health impact assessments would allow individuals working within, or across, different levels of government to have access to tools or methods that could be used for a range of analyses, based on their needs for different assessments. This report does not prescriptively identify which reduced-form tools used elsewhere should be developed in the Canadian context, as this decision should be made with stakeholders, air quality and health impacts modelling experts, and actors across different levels of government.

While these tools would support greater accessibility of analyses, they would only facilitate sections of the four step approach outlined above. Canadian BPT/B-kWh estimates would be beneficial in simplifying evaluations of health outcomes resulting from changes in air quality. Governments should also develop Canadian BPT/B-kWH estimates to facilitate this analysis. These Canadian BPT/B-kWh estimates would need to be pollutant specific, should encompass pollutant emissions from a range of energy sources across Canada including electricity, gasoline, diesel and natural gas, and regularly updated in line with the pace of scientific advancement and demographic changes to ensure they were representative of average impacts on the current population of a given community. The development of these estimates in Canada would dramatically simplify an analysis of the health impacts associated with reducing pollutants within a given region, and would lower the time and resource costs of credible stakeholder estimates of health benefits of reducing air pollution, which could inform decisions about investing in low-carbon infrastructure.

This report recommends that Canadian governments and experts develop Canada-specific reduced-form tools for stakeholder use in assessments of changes in air quality and health effects.

CONCLUSION

As Canada transitions to net-zero emissions by 2050, stakeholders across the country will make investments into low-carbon infrastructure projects that reduce emissions and support cleaner growth. Given the potential for low-carbon infrastructure projects to support improvements in air quality and community health, ensuring stakeholders have the tools available to them to undertake assessments of potential health impacts is critical to ensure stakeholders across Canada can identify and capture the full suite of benefits emerging from projects. Moving forward, Canadian stakeholders would benefit from the development of Canada-specific reduced form tools, techniques, and methods that reduced the time and resource costs associated with undertaking analyses of the health impacts of low-carbon infrastructure projects.

APPENDIX 1: SECTORS AND SUBSECTORS OF CITY EMISSIONS

According to the SMOKE modelling documentation, emission inventories are traditionally divided in the following source categories:

Source category	Subsector
Stationary area/Nonpoint sources (These are sources treated as being spatially spread)	• Residential heating • Architectural coating • Commercial buildings and facilities (e.g, dry cleaning facilities)
Mobile sources (Vehicular and otherwise movable sources)	• Nonroad mobile sources (locomotives, lawn and garden equipment, construction vehicles, boating emissions) • On-road mobile sources (light-duty gasoline vehicles and heavy duty diesel vehicles)
Wildfire sources	• Wildfires with plume rise
Point sources (These are point locations that are often subject to regulation)	• Electric generating utilities • Chemical manufacturers • Furniture refinishers
Biogenic land use data	• Livestock • Land • Aggregate sources and non-CO_2 emission sources on land

Sources: The Institute for the Environment (2015).

Some other well renowned guiding documents use the following terminology to categorize source of emissions by sectors and subsectors of city emissions:

Sector	Subsector
Stationary energy	• Residential buildings • Commercial and institutional buildings and facilities • Manufacturing industries and construction • Energy industries • Agriculture, forestry, and fishing activities • Non-specified sources • Fugitive emissions from mining, processing, storage, and transportation of coal • Fugitive emissions from oil and natural gas systems
Transportation	• On-road • Railways • Waterborne navigation • Aviation • Off-road
Waste	• Solid waste disposal • Biological treatment of waste • Incineration and open burning • Wastewater treatment and discharge
Industrial Processes, Solvent and Product use	• Industrial processes • Product use
Agriculture, forestry, and other land use	• Livestock • Land • Aggregate sources and non-CO_2 emission sources on land

Sources: The Global Protocol for Community-Scale Greenhouse Gas Emission Inventory (WIR, 2014: 31) and the Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amount (UNFCCC, 2008: 106).

There is a lot of overlap between the two tables in this appendix. This report refrains from suggesting a specific terminology and categorization scheme, as the correct sector classification will vary based on the needs of each analysis. Both forms of categorizing are advocated for by equally authoritative sources for both GHG and air pollutant inventory construction. Whichever classification is selected, stakeholders should use the terminology and categorization scheme of choice in a consistent form.

APPENDIX 2: LIST OF DATABASE/SOURCES FOR EMISSIONS FACTORS OF GHGS AND AIR POLLUTANTS

The following is a non-exhaustive list of databases and tools that compile emissions factors, from both Canada and credible international sources. These databases contain a mix of both AEFs and MEFs, and it is recommended stakeholders identify which emissions factors are best suited to their analysis by consulting sources of country-specific data for guidance.

List of database/sources for emissions factors of GHGs and air pollutants

	Canada	**International**
Greenhouse gas emissions	National Inventory Report: Greenhouse Gas Sources and Sinks in Canada - Part II and III Canada's Official Greenhouse Gas Inventory Canada's 2018 Greenhouse Gas and Air Pollutant Emissions Projections Alberta's Carbon Offset Emission Factors Handbook A Guidance Document for Reporting Greenhouse Gas Emissions for Large Industry in Newfoundland and Labrador British Columbia's guide to development of the greenhouse gas emissions (GHG) emission factors Manitoba Hydro Emissions Factor for electricity and natural gas Ontario's Guideline for Quantification, Reporting and Verification of GHG Emissions A Clear View on Ontario's Emissions (Average and Marginal Electricity Emission Factors) Quebec's Emissions Factor, by type of energy	IPCC Emission Factor Database EPA's 2020 Emission Factors for Greenhouse Gas Inventories EPA's Center for Corporate Climate Leadership GHG Emission Factors Hub
Air pollutants	National Pollutant Release Inventory Air Pollution Emission Inventory	EPA's Compilation of Air Pollutant Emissions Factor EPA's Emission Factor Search Engine EPA's National Emissions Inventories
GHGs and air pollutantS	N/A	EPA's Avoided Emissions and Generation Tool (AVERT)* EPA's Clearinghouse for Inventories and Emissions Factors (CHIEF) EPA's Emissions & Generation Resource Integrated Database (eGRID) EPA's Motor Vehicles Emissions Simulator (MOVES)

* Note that some tools used to quantify carbon emissions provide both national and regional average emissions factor (AEFs) and marginal emission factors (MEFs), such as the case of AVERT.

APPENDIX 3: GUIDELINES AND PROTOCOLS FOR INVENTORIES AND EMISSION ANALYSIS

This appendix lists and summarizes a number of reference guides and protocols that establish world-renowned standards and best practices for the development of emissions inventories and for conducting accounting practices.

1996/2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines): The Guideline sets best practices for the estimation and reporting of anthropogenic greenhouse gas emissions. The 2006 IPCC guidelines can be found in this link.

Compendium on Greenhouse Gas Baselines and Monitoring: Developed by UNFCCC, this compendium is an essential tool for stakeholders who seek a robust methodology to collect GHG quantification and mitigation measures to reduce emissions in the transport sector. The compendium can be found here.

GHG Protocol for Cities: An Accounting and Standard Report for Cities (GPC): An authoritative source, the GPC establishes credible emissions accounting and reporting practices that help municipalities develop an emissions baseline, set mitigation goals, and track progress over time. The GPC can be downloaded from this link.

The PCP Protocol: Canadian Supplement to the International Emissions Analysis Protocol: This Protocol aims to provide stakeholders with a set of accounting and reporting guidelines for developing community-level GHG inventories. It can be found here.

US Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions: This is the equivalent of GPC above, but focused on US specificity. The US Protocol and additional resources such as on-demand training can be found here.

Local Government Operations Protocol for the Quantification and Reporting of GHG Inventories: This is a protocol designed to assist local governments in quantifying and reporting GHG emissions associated with government activities and operations. The Local Government Protocol can be downloaded here.

International Local Government GHG Emissions Analysis Protocol (IEAP): This Protocol provides an accessible set of guidelines to assist local governments in quantifying the GHG emissions and establishing inventories. The IEAP can be found here.

International Standard for Determining Greenhouse Gas Emissions for Cities (ISDGC): It provides consistent reporting formats for GHGs from cities and local regions. ISDGC can be downloaded here.

Baseline Emissions Inventory/Monitoring Emissions Inventory Methodology (BEI/MEI): It allows the quantification of CO_2 emissions. The Guidebook can be found here.

PAS 2070: Specification for the Assessment of a Greenhouse Gas Emissions of a City: It provides two methodologies to calculate the emissions from a city: a bottom-up and a top-down approach to calculate emissions. PAS 2070 can be downloaded here.

APPENDIX 4: METHODS FOR EVALUATING HEALTH BENEFITS

Non-exhaustive list of reports and databases containing tools to support assessment of health benefits

Report/Database	Country	Region	Sector-focus	Resource
Health Canada's Air Quality Benefits Assessment Tool (AQBAT)*	Canada (applicable for use in Canada)	National and regional scale	Non-sector specific	Customizable excel tool.
Reduced-Form Tools for Calculating PM2.5 Benefits[53]	United States	National and regional scale	17 sectors	List of BPT estimates
Monetized health benefits attributable to mobile source emission reductions across the United States in 2025[54]	United States	National and Regional (East and West)	16 mobile-source sectors (transportation is broken down into sub-sectors including air, marine, rail and heavy-duty trucking)	List of BPT estimates
EASIUR Model estimating social benefits from reducing elemental carbon (i.e. primary PM2.5), SOx, NOx and ammonia.	United States	National and regional scale	Non-sector specific	Multiple features with varying levels of complexity, including a simple-to-use online tool.
World Health Organization's AirQ model for calculating PM2.5, PM10, NO2, O3 and Black Carbon	Available/ customizable for use in all WHO regions (including Canada)	Can be regionally customized using GIS tools.	Non-sector specific	Customizable excel tool.
United States EPA Benefits Mapping and Analysis Program (BenMAP)	United States, but can be customized for use in other regions	Dependent on geography selected, but there are geographic datasets for a number of regions/countries.	Non-sector specific	Open-source online tool.
Open-source Intervention Model for air pollution (InMAP)	United States	Regionally customizable	Non-sector specific	Open-source tool.

* Note: The Air Quality Benefits Assessment Tool (AQBAT) was developed by Health Canada to estimate the human health impacts of ambient air quality changes. It is the most authoritative application tool used in Canada.

APPENDIX 5: GLOSSARY OF TERMS

This glossary includes key terms for undertaking the analyses outlined in this report in Canada. It should be noted that terms for concepts may differ depending on the country of origin where resources were developed.

Activity data: An activity provides a service or a product. Activity data refers to a value of measure representing the level of activity that results in emissions. Common examples of activity data include kilowatt-hours of electricity used, distance travelled, quantity of fuel used, area of solar panel, and floor area of a building.

Average emissions factor (AEF): A value representing the average emissions intensity of a specific activity throughout the course of a year. Average emission factors are mostly used in simple calculations to estimate the emissions from a particular activity without necessarily measuring the impact or consequences of the implementation of a low-carbon project. They are usually sourced from secondary databases or tools used to quantify emissions, such as AVERT.

Avoided electricity generation: This refers to the net energy savings of a specific program. When multiplied by emission factors, it calculates the avoided emissions of a low-carbon programs or project.

Benefit-per-tonne: This refers to estimates that represent health benefits, often in monetized terms, of avoiding one ton of emissions from a particular source.

Baseline health outcomes: An estimate of the average number of people who experience an adverse health impact in a given population over a set period of time.

Baseline of emissions: The baseline of emissions refers to the set of emissions projections used as a benchmark for the analysis of the impact of different policy scenarios.

Baseline year: The year against which a municipality tracks its emissions over time.

Bottom-up method for inventory development: An accounting decision to develop an inventory with sector-specific data for emissions from source, equipment use, or activity. A bottom-up inventory is used to generate estimates of air pollutant and GHG emissions specific to the sector of interest, providing more granularity in estimates, projections, and analysis.

Capacity factor: A measure of the frequency that an electric generating unit runs for a given period of time.

Carbon dioxide equivalence (CO_2e): A common unit of measurement used to represent greenhouse gas emissions. Using CO_2e estimates when developing an emissions baseline allows for the total warming potential of all greenhouse gas emissions in an inventory to be represented using a single value.

Co-benefits: The spillover positive effects associated with a policy, project or program aimed at a particular goal.

Concentration-response function (CRF): A statistically derived estimate that quantifies the impact of a pollutant on a specific health endpoint. It represents the relationship between the exposure to given pollutant and the associated adverse health impacts to a given population brought on by this exposure.

Contaminants of potential concern: These are contaminants with strong evidence of posing risks to human or animal health**.**

Criteria air contaminants (CACs): Hazardous emissions that contribute to air pollution and which are regularly recorded by governmental authorities such as Environment Canada.

Emission Factor: These are values used to represent the mass of emissions released as a result of each unit of an activity. The emission factor is the ratio between the amount of pollution generated and the amount of a given raw material processed. The term may also refer to the ratio between the emissions generated and the outputs of production processes. Emission factors are used to convert activity data into emissions data.

Emissions levels: A value representing the amount of emissions released into the atmosphere from various sources

Exposed population: the number of people affected by an air pollutant in a given region.

Exposure: The presence of air pollution that adversely affects populations. It involves the contact with a chemical.

Global Warming Potential (GWP): A measure of how much energy the emissions of 1 tonne of a given gas will absorb over time, relative to 1 tonne of carbon dioxide.

Health Co-Benefits: Ancillary positive health effects that result from policies, projects or programs aimed at reducing greenhouse gas emissions, supporting greater environmental conservation or supporting cleaner economic growth.

Marginal emissions factor (MEF): A value representing the amount of emissions displaced by the introduction of a low-carbon infrastructure such as energy efficiency or renewable energy programs or technologies. Marginal emission factors are used to more accurately estimate the impact of projects or decisions on the environment. As such, marginal emission factors (MEF) are preferred over average emission factors (AEF) in environmental impact analysis.

Pollution concentration changes: A measure of the change in concentrations of air pollutants in ambient air that result from a reduction in emissions of greenhouse gases/air pollutants.

Precursor emissions: This refers to emissions of gaseous pollutants that, in the presence of sunlight or in hot atmospheric conditions, originate secondary pollutants through complex chemical reactions.

Project scenario: A project scenario is a set of projections based on alternative assumptions than those used in the baseline. It is used to provide information on the impact of changes should a project or policy be implemented.

Reduced form methods: These refer to a set of simplified tools and strategies that take the output of complex models or existing studies to facilitate the quantification of air quality changes or health impacts from these changes. These methods allow the extrapolation of rough estimates from a single case study to other cases, expediting and simplifying cost-benefit analysis.

Scope: This refers to an account technique that separates emissions by geographical and activity sources. To avoid double-counting, emissions are accounted as scope 1 (emissions from sources located within the jurisdiction boundaries), scope 2 (emissions as a consequence of use of grid-supplied electricity, heat, steam/cooling within the jurisdiction boundaries), or scope 3 (emissions that occur outside of the jurisdiction, but as a result of activities taking place within its boundaries).

Top-down method for inventory development: An accounting decision to develop an inventory with aggregated data across the jurisdiction. A top-down inventory is used to generate municipality-wide estimates of air pollutant and GHG emissions.

ENDNOTE CITATIONS

1 Martin and Riordan, 2020.
2 New Climate Institute, 2018.
3 Sergi et al., 2020.
4 Aldy et al., 2020.
5 Barn et al., 2011.
6 This position was reflected amongst discussions with municipal stakeholders, and air pollution modelling experts across Canada.
7 Metro Vancouver, 2015.
8 Environmental Protection Agency, 2018.
9 World Health Organization, 2020.
10 Health Canada, 2021.
11 In 2020 Canadian dollars.
12 For greater detail on the topic, read Smart Prosperity's report entitled "The health co-benefits of a clean growth future" (Coutinho, McGillivray & Ramesh, 2021).
13 Health Canada, 2021.
14 Ibid.
15 Laszlo et al., 2016.
16 Fong et al., 2014.
17 United Nations Climate Change, 2020.
18 Environmental Protection Agency, 2018.
19 Government of Canada, 2011. Health Canada, 2016.
20 Coutinho, McGillivray and Ramesh, 2021.
21 Environment and Climate Change Canada, 2018.
22 The Institute for the Environment, 2015.
23 Environmental Protection Agency, 2018.
24 Canada Energy Regulator, 2020.
25 Fong et al., 2014.
26 Partners for Climate Protection, n.d.
27 Environmental Protection Agency, 2018.
28 These characteristics were summarized from Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy (Environmental Protection Agency, 2018) and Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (Fong et al., 2014).
29 Gillingham, Rapson and Wagner, 2016.
30 Environmental Protection Agency, 2018.
31 Environmental Protection Agency, 2018.
32 SEE Action, 2012.
33 Edenhoer et al., 2014; Zhao et al., 2019.
34 These considerations were summarized from Guidance for Evaluating Human Health Impacts in Environmental Assessment: Air Quality (Health Canada, 2016) and Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy (Environmental Protection Agency, 2018).
35 Government of Alberta, 2020.
36 Environmental Protection Agency, n.d.
37 Landis et al., 2012.
38 Environmental Protection Agency, 2020a.
39 Environmental Protection Agency, 2020b.
40 Jeong et al., 2011.
41 Cho et al., 2019; Smyth et al., 2009.
42 Government of Canada, 2007.
43 Government of Canada, 2020
44 Lundgren et al., 2012.
45 Foley et al., 2014.
46 Idem.
47 Health Canada, 2019a: 25.
48 Health Canada, 2019b.
49 In Canada, these social values are represented by figures taken from studies that conduct analyses of surveys, accounting, economic or actuarial data (Health Canada, 2019a); see also Fowler et al., 2017.
50 Health Canada, 2021.
51 Alberni, Bigano & Post, 2015.
52 Wolfe et al., 2019.
53 This webpage from the US Environmental Protection Agency contains a number of links to reports, technical documents and studies with BPT estimates of reducing PM 2.5 and PM2.5 precursors (NOx and SOx) at both a national and regional scale. These studies include a number of sectors.
54 This 2019 study offers BPT estimates of PM2.5 and PM2.5 precursors including NOx and SOx (Wolfe et al., 2019).

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