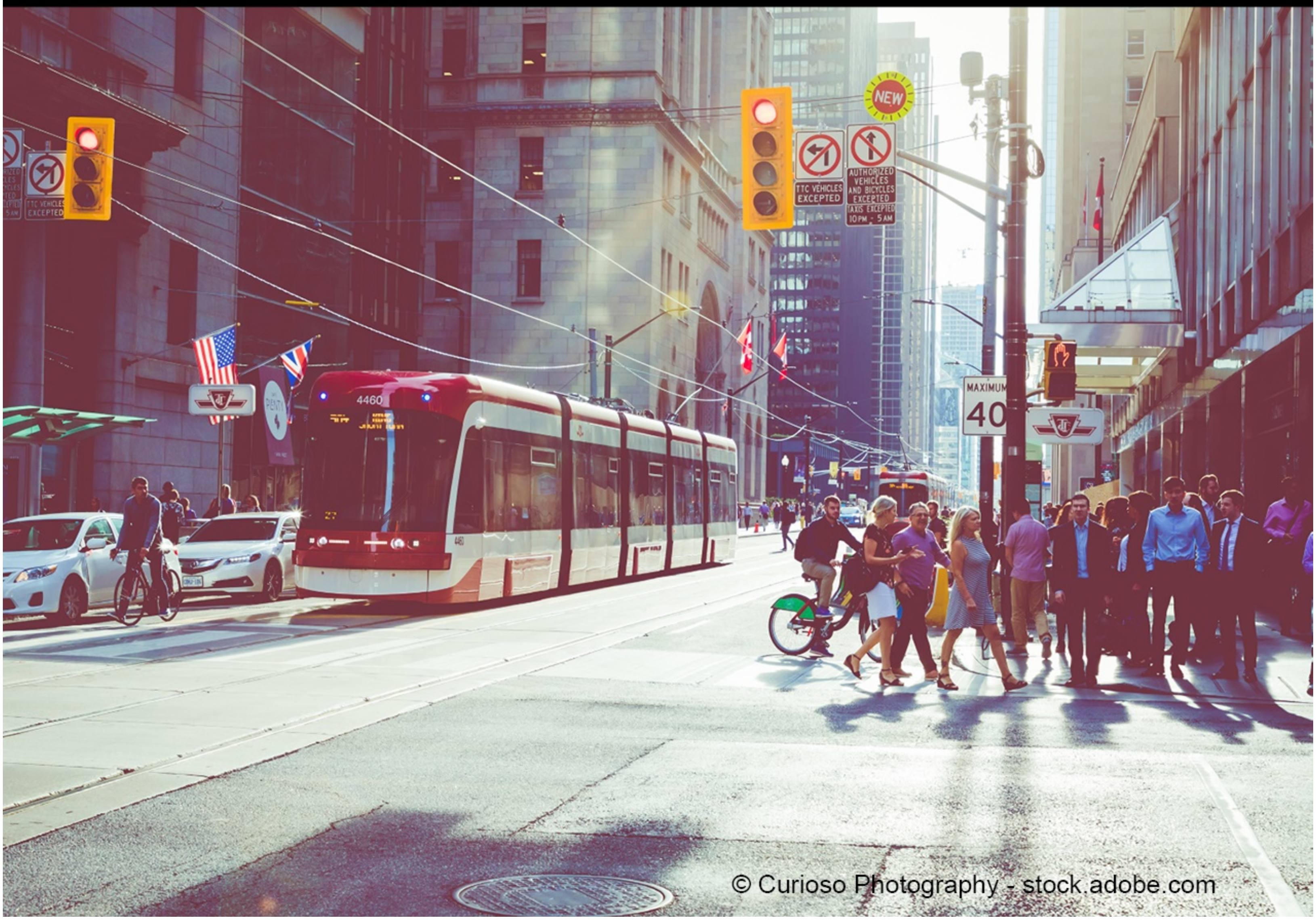
Benefits of Actions to Reduce Greenhouse Gas Emissions in Toronto: Health and Health Equity



Prepared for the City of Toronto by the Canadian Urban Institute |
30 St. Patrick St, Toronto, ON M5T 3A3 | www.canurb.org | March 15, 2019

Reference: City of Toronto. *Benefits of actions to reduce greenhouse gas emissions in Toronto: Health and health equity*. March 2019.

This report was prepared for the Environment & Energy Division of the City of Toronto. It is one report in a series of studies exploring the benefits of greenhouse gas reduction actions in Toronto under the City's TransformTO strategy.

TABLE OF CONTENTS

Executive Summary

Climate change has been described as the "biggest global health challenge of the 21st century" (Watts et al. 2018). Understanding and conveying the linkages between actions to reduce greenhouse gas (GHG) emissions and their impact on health is key to demonstrating the importance of reducing emissions and increasing support for mitigation actions. This report outlines the most feasible approaches for the City of Toronto to demonstrate linkages between actions being taken under TransformTO, the City's climate action strategy, and the health and health equity co-benefits of undertaking those actions.

Based on the findings of an in-depth literature review, impact statements were created to describe linkages for actions across seven categories: building retrofits; the Toronto Green Standard; district energy system (DES) installations; decentralized renewable energy; active transportation infrastructure; public transit infrastructure/investments; and electric vehicles. The impact statements can be used by the City to demonstrate the expected health benefits of TransformTO initiatives.

Study Approach

This study was conducted over two phases with the objective of identifying a method (framework) that the City of Toronto can use to quantify health and health equity benefits of actions that are being taken to reduce GHG emissions in Toronto under TransformTO. In the first phase, a literature review of over 100 resources was completed, along with a jurisdictional scan and interviews with other cities conducting similar research. Results from the first phase suggested that this is an emerging but prominent area of study, where the City of Toronto has the opportunity to be a global leader while developing a made-in-Toronto approach. In this second phase of the study, specific recommendations and impact statements are provided for the City. Their development is informed by the findings of the first phase and consultation with the Project Advisory Group.

Findings and Recommendations

Through our review, we found that the literature on quantifying health and health equity co-benefits of GHG-reduction actions is marked by strong connections between GHG-reduction actions and health co-benefits across diverse cities, with less available research on health-equity benefits. Although the co-benefits quantified in other jurisdictions cannot be directly applied to Toronto without adjusting for local context, broad trends are observed that link climate actions to specific co-benefits. Specifically, we found that physical and mental health are frequently improved from health drivers of improved outdoor and indoor air quality, increased physical activity, reduced traffic noise, and decreased motor vehicle traffic. The impact statements developed as part of the second phase of this study can be used by the City to convey these trends.

Overall, five key findings and recommendations were derived:

1. The quantification of health and health equity co-benefits of GHG-reduction actions is an emerging and growing field of study.
2. The quantified health and health equity co-benefits of GHG-reduction actions identified in other jurisdictions cannot be directly applied to Toronto without using local data. However, trends were observed in the research which link GHG-reduction actions and health and health equity co-benefits. These linkages could be expected to exist in Toronto.
3. The City can demonstrate the expected health benefits of TransformTO initiatives by using research-supported general linkages (impact statements) that connect GHG-reduction actions with health and health equity co-benefits. Impact statements are presented in this report.
4. The City can explore existing data sources and the possibility of conducting an original research study with partners to quantify the potential health and health equity impacts of GHG-reduction actions in Toronto and establish a baseline for reporting progress on TransformTO.

1. Purpose

This report provides recommendations on feasible approaches for the City of Toronto to link health and health equity co-benefits to actions being taken under the City's climate action strategy, TransformTO. Based on the findings from an in-depth literature review, impact statements were created for actions across seven categories of strategies being employed by the City of Toronto to reduce greenhouse gas (GHG) emissions:

- Building retrofits;
- Toronto Green Standard;
- District Energy System (DES) installations;
- Decentralized renewable energy;
- Active transportation infrastructure;
- Public transit infrastructure/investments; and
- Electric vehicles.

These impact statements demonstrate the expected trends of health and health equity co-benefits that can arise from GHG-reduction actions. They are supported by universal trends and findings from research conducted in other jurisdictions.

This report summarizes the findings from the second phase of a study commissioned by the City of Toronto, Environment & Energy Division (EED) and conducted by the Canadian Urban Institute (CUI) to identify a method (framework) that the City can use to quantify health and health equity benefits of actions that are being taken to reduce GHG emissions. In the first phase of the study, frameworks and approaches used in other jurisdictions and by international networks/organizations to quantify health and health equity co-benefits were compiled, reviewed, and assessed. The findings of this literature review inform the recommendations presented in this report.

Image 1 Curioso Photography - stock.adobe.com

2. Background

The City of Toronto EED is currently implementing TransformTO, the climate action strategy for securing a healthy, equitable, and prosperous future for Toronto. The vision of the strategy is to create a low-carbon Toronto that is healthy for all residents and visitors. The strategy is based on a series of GHG-reduction actions to achieve the long-term target of reducing GHG emissions in Toronto by 80% by 2050, relative to 1990 levels.

The 2018 report of the *Lancet Countdown on health* indicates that “climate change is the biggest global health challenge of the 21st century” (Watts et al. 2018). Implementing the GHG-reduction actions of TransformTO provides an important opportunity to not only reduce the City’s GHG emissions but also to generate health and health equity co-benefits in Toronto and beyond. Climate action under TransformTO will also create positive impacts on economic prosperity and climate resilience, which are being evaluated in separate studies.

Conveying the co-benefits of GHG-reduction actions will be an important part of reporting progress in implementing TransformTO, and how the City measures success. Toronto City Council has directed City staff to report on TransformTO's key performance indicators, including benefits, every two years (City of Toronto 2017b). Reporting on co-benefits is important for cities and their residents to understand the wide-reaching impacts of climate change mitigation strategies. More specifically, making the case for climate action is often most effective when the effects of climate change are connected to the everyday lives of residents (e.g. health improvements). This broadened understanding will increase the likelihood of individuals and organizations acting on and building the case for change.

3. Methodology

In the first phase of this study, CUI conducted a literature review of more than 100 peer-reviewed academic studies and multi-industry reports published by government agencies and non-governmental organizations. CUI also conducted a jurisdictional scan and contacted the environment and climate change divisions of the following four municipalities: New York City, Greater London Authority, the City of Vancouver, and the City of Edmonton. Our team also contacted Montréal's Public Health Department, which is technically independent of the municipality. As part of the second phase, over 60 additional studies and reports were evaluated to inform the recommendations and impact statements in this report. The methodology used to conduct the literature review and jurisdictional scan is described in detail in the report from phase one, which may be requested from the City. Findings from 20 select studies that were reviewed in this project's first phase are summarized in Table 1, attached in Appendix A.

CUI and EED also consulted with a Project Advisory Group who provided input during the project. The Advisory Group included representatives from EED (Existing Buildings and New Development), Toronto Public Health, City Planning, Transportation Services (Cycling Infrastructure and Programs and Pedestrian Projects), and the Atmospheric Fund.

4. Findings & Recommendations

The following key findings and recommendations have been developed through our research and consultation with the Project Advisory Group.

4.1 Quantification of Health and Health Equity Co-Benefits

1. **The quantification of health and health equity co-benefits of GHG-reduction actions is an emerging and growing field of study.**

   Evaluating the health and health equity co-benefits of GHG-reduction actions is an emerging area of study that is beginning to influence policy and government decision-making. There is currently no internationally, nationally, or provincially standardized method for quantifying health co-benefits. In the absence of a standardized method, the City has the opportunity to lead by example and develop a "made in Toronto" approach.

2. **The quantified health and health equity co-benefits of GHG-reduction actions identified in other jurisdictions cannot be directly applied to Toronto without using local data. However, broad trends were observed in the research which link GHG-reduction actions with health and health equity co-benefits. These linkages could be expected to apply to similar actions taken in Toronto.**

   The findings from our review of academic and professional resources suggest that standard multipliers for calculating health and health equity co-benefits of actions to reduce GHG emissions are not available.

   All the literature reviewed on health benefits of GHG-reduction actions draws on locally sourced data to account for local population health, climate conditions, and policy interventions. For example, a recent review publication – *Public health co-benefits of greenhouse gas emissions reduction: A systematic review* reported that, “due to variations in study design, mitigation scenarios, exposure-response functions, model assumptions and selection of methods, it is often difficult to compare health co-benefits assessments even if the study area and target time scales are identical” (Gao et al. 2018).

   Through the jurisdictional scan, we also found that very few local governments have quantified health benefits of GHG-reduction actions themselves, and none, to our knowledge, have quantified the health equity benefits. Further, while it has been widely discussed in academic and grey literature that health disparities are exacerbated by social and economic inequity (i.e. the adverse health impacts of climate change are disproportionately borne by marginalized populations), very few studies to date have evaluated the health equity co-benefits of GHG-reduction actions. A select number of studies have acknowledged that co-benefits will likely differ by population but have not discussed health equity as a health endpoint (Howden-Chapman et al. 2004; Hamilton et al. 2015; Day et al. 2018).

While the results from studies conducted in other jurisdictions cannot be directly applied to Toronto without accounting for local conditions, some trends were observed repeatedly in the research which linked GHG-reduction actions to certain health and health equity co-benefits. As the City requires a methodology that can be executed by staff in 2019 at minimal cost, we focused our research efforts on identifying research-supported linkages between GHG-reduction actions and health and health equity co-benefits that could apply to Toronto. These linkages are provided in the impact statements presented in this report.

4.2 Frameworks & Approaches

3. **The City can demonstrate the benefits of TransformTO initiatives by using research-supported general linkages (impact statements) that connect GHG-reduction actions to health and health equity co-benefits.**

   In tracking the progress of TransformTO, the impact statements developed for this report can be used to demonstrate the trends in heath and health equity co-benefits from GHG-reduction actions. This approach can be implemented at a minimal cost to the City. The linkages between climate actions and co-benefits are supported by research and evidence from other jurisdictions. Through the research, we repeatedly observed consistent trends that link GHG-reduction actions to health and health equity co-benefits. While the statements do not explicitly quantify these co-benefits, they serve an important function by drawing the conceptual linkages between health outcomes and actions to reduce GHGs. In this way, they represent a crucial starting point for understanding the potential health benefits that could be achieved through climate actions under TransformTO.

4. **The City should explore existing data sources and the possibility of conducting an original research study with partners to quantify the potential health and health equity impacts of GHG-reduction actions in Toronto and establish a baseline for reporting progress on TransformTO.**

   The City should begin to catalogue and monitor the range of available data sources that could be leveraged to quantify health and health equity co-benefits and report on progress in implementing TransformTO. Specifically, the City should explore opportunities for collecting data on key metrics that have been previously used to quantify health benefits. This includes the collection of baseline data on specific health drivers (e.g. air pollutant concentrations, modal share by trips, motor-vehicle traffic, and traffic noise) that are related to the climate action strategy. Leveraging data is a crucial first step if the City wishes to quantify and report on co-benefits of reducing GHG emissions under TransformTO.

   In order to meaningfully develop a “made in Toronto” approach, the City could also explore the possibility of conducting an original research study, with partners, that draws on available data sources and takes into account local population, health, and environmental conditions.[1] In doing so, the City could adopt a Burden of Disease (BoD) framework, which is endorsed by the World Health Organization (WHO) and widely adopted in health co-benefits studies, to quantify the burden of premature mortality and disease that could be avoided through GHG-reduction actions. This would result in quantitative estimates of health burdens that could be compared with other jurisdictions and used by the City to measure progress.

Health co-benefits studies range in complexity. Deriving basic quantitative measures of health burdens that could be avoided under TransformTO could be produced using secondary data sources (e.g. clinical data from the Ontario healthcare system, population data and life tables published by Statistics Canada, exposure-response functions from the epidemiological literature). If time and resources permitted, the City could also partner with a university or research organization to conduct primary research. Either of these options would help verify whether broad findings from the literature on health co-benefits are applicable in Toronto and ultimately determine the co-benefits of actions to reduce GHG emissions.

4.3 Health & Health Equity Co-benefit Impact Statements

As the findings of this study suggest that coefficients to quantify health and health equity co-benefits of actions to reduce GHG emissions are not readily transferable from other jurisdictions to Toronto, we are providing impact statements for each GHG-reduction action category identified by the City of Toronto. These statements convey the expected trends in health and health equity co-benefits linked to each category. The statements were developed based on the findings of previous studies and a summary of the supporting research is provided for each.

We found in the first phase of this study that health equity co-benefits of GHG-reduction actions are not commonly quantified in either the academic or grey literature. For this reason, there are fewer impact statements on health equity. A general finding from the first phase was that actions to mitigate climate change will likely provide greater health benefits to more vulnerable populations, such as children and older adults, and help close the inequality gap (Howden-Chapmen et al. 2004; Wilkinson et al. 2009; Hamilton et al. 2015). Understanding the potential higher risks to vulnerable populations in Toronto, through vulnerability assessments, will be key for the City to track health equity impacts of climate change interventions.

As discussed, the results of the literature reviewed are specific to the jurisdictions in which the studies were conducted. Although trends in health benefits related to GHG-reduction actions can be derived, specific values will differ based on local conditions. For example, the potential health co-benefits from improved air quality associated with energy conservation will depend on the energy supply mix of that

[1] The City has done a similar study in the past; see: Toronto Public Health. *Path to Healthier Air: Toronto Air Pollution Burden of Illness Update*. Technical Report. April 2014.

area. Toronto's energy is supplied primarily by electricity and natural gas (City of Toronto 2015). Ontario has made significant progress in lowering emissions from electricity generation by phasing out coal-fired plants starting in 2005. By 2017, Ontario's electricity generation was 96% emission-free (nuclear, hydro and renewables) (ECO 2018). As a result, concentrations of air pollutants have decreased considerably, where electricity generation alone now produces almost zero sulphur dioxide (SO_2) (ECO 2018). However, natural gas continues to be used for space and water heating in Toronto buildings and, in 2013, comprised over 60% of Toronto's overall energy consumption (City of Toronto 2015).

Most existing health co-benefits studies have been conducted in jurisdictions where the energy mix is still at least partially supplied by coal-fired plants. Burning coal emits a much higher amount of GHGs and associated air pollutants (SO_2, NO_x and $PM_{2.5}$) than burning natural gas. Consequently, the predicted health benefits of energy conservation in these studies are expected to be greater than in Ontario where coal has already been phased out. However, some of the demonstrated trends in health benefits can still be relevant to Toronto where natural gas remains a key energy source. Although natural gas has the lowest carbon content of any fossil fuel and emits negligible sulphur dioxide (SO_2), burning natural gas still produces greenhouse gases and air pollutants, including nitrogen oxides (NO_x) and precursors to fine particulate matter ($PM_{2.5}$) and ground-level ozone (O_3) (Alvarez & Paranhos 2012). For example, residential and commercial buildings are estimated to be the second largest local contributor to air pollution-related health impacts in Toronto, second only to traffic. Local emissions from these buildings are primarily from burning natural gas to heat buildings and water (Toronto Public Health 2014). Reducing natural gas consumption in Toronto has the potential to reduce local air pollutant emissions and contribute to reducing the health burden from air pollution in Toronto.

4.3.1 Building Retrofits

Worldwide, buildings account for 30% of energy-related GHG emissions and 40% of primary energy consumption (MacNaughton et al. 2018). In Toronto, buildings are responsible for approximately half of all GHG emissions, primarily from electricity and natural gas consumption (City of Toronto 2019). Furthermore, of the total building floor space that will exist in 2050, over 80% has already been built (City of Toronto 2017b). Consequently, TransformTO's long-term goal to retrofit 100% of buildings to the highest emission reduction standards technically feasible is key for reaching the City's 2050 emissions target.

Health and health equity co-benefits of building retrofits are typically quantified based on improvements to indoor air quality and reductions in outdoor air pollutants. Impacts on outdoor air pollution from increased energy conservation differs depending the fuel mix of the energy consumed. In Toronto, natural gas accounts for an estimated 60% of building energy use and electricity accounts for 39% (SSG 2016). With the phase out of coal and a resulting clean electrical grid, the key health drivers of energy conservation from building retrofits in Toronto are expected to be reductions in natural gas consumption and associated air pollutants NO_2, $PM_{2.5}$ and O_3. Toronto Public Health indicates that the residential and commercial building sectors together are the second greatest contributor to health impacts of air pollution from sources in Toronto and responsible for 28% of premature deaths and 20% of hospitalizations arising from pollution emitted in Toronto. This is primarily from burning natural gas to heat homes and buildings and to heat water (Toronto Public Health 2014).

Some of the studies used to support the impact statements for building retrofits and the Toronto Green Standard evaluate conditions where coal is part of the energy mix. However, as previously discussed, health trends from the air pollutants NO_x and $PM_{2.5}$, which are both associated with burning coal and natural gas (although at higher intensities with coal), will be relevant to Toronto. There are also multiple studies that include both coal and natural gas (Wiser et al. 2013; MacNaughton et al. 2018).

Building energy retrofits (e.g. improved insulation and ventilation, heating and cooling repairs, and window upgrades), reduce energy use, which has shown to improve outdoor air quality by decreasing air pollution associated with fossil fuel combustion (Nemet et al. 2010; European Commission 2013; MacNaughton et al. 2018). Reduced concentrations of air pollutants $PM_{2.5}$, NO_x and ground-level ozone can decrease the incidence of respiratory and heart disease, cancer, and premature death (Nemet et al. 2010; European Commission 2013; MacNaughton et al. 2018).

IMPACT: *Building energy retrofits can reduce outdoor air pollutants associated with electricity and natural gas consumption and as a result benefit physical health.*

Improvements to a building's envelope, and heating, ventilation, and air conditioning systems can also improve indoor environmental quality. These retrofits can improve thermal comfort and reduce indoor air pollutants (NO_x, CO, and VOCs), dampness, and annoyance and disturbance from noise. Associated health benefits include improved mental well-being, decreased mental disorder, and reduced risk of cardiovascular, endocrine, respiratory, cancer, and cardiopulmonary illnesses (Allen 2005a; Howden-Chapman et al. 2004; Barton et al. 2007; Bonnefoy 2007; Wilkinson et al. 2009; Zharna & Guilleminault 2010; Gilbertson et al. 2012; Hamilton et al. 2015; Becchio et al. 2018).

IMPACT: *Building retrofits can benefit the physical and mental health of residents by improving indoor air quality and reducing dampness and exposure to noise.*

Insulation retrofits in low-income communities can be an effective approach to adjust the unequal distribution of health risks within a population and reduce fuel poverty (Howden-Chapman et al. 2004; Sharif et al. 2016). Occupants of older and poorly constructed houses are more likely to be of lower socioeconomic status, compounding health impacts of inadequate insulation, and less likely to have resources for intervention (Howden-Chapman et al. 2004). Therefore, public programs that support building insulation retrofits have the potential to improve the mental and physical health, as discussed above, of more vulnerable populations (Howden-Chapman et al. 2004; Sharif et al. 2016). Building retrofit financing programs in Toronto include the Home Energy Loan Program (HELP) for single-family homes and the High-rise Retrofit Improvement Support Program (Hi-RIS).

***IMPACT:** Improvements to insulation of poorer quality homes can improve the physical and mental health of vulnerable populations and reduce energy poverty.*

UNITED KINGDOM

In the United Kingdom, Hamilton et al. (2015) estimated that retrofits for19 million households would result in 2,241 QALYs gained per 10,000 people over 50 years, and a 30% reduction in annual heating-related energy demand. The types of retrofit for which households were eligible included: double glazing, cavity insulation, solidifying walls and lofts, adoption of new condensing gas boilers, and improvements that prevent air leakage (Hamilton et al. 2015).

Image 2 © xvan72 - stock.adobe.com

4.3.2 Toronto Green Standard

Buildings are responsible for almost half of Toronto's GHG emissions (City of Toronto 2019). TransformTO identifies long-term goals to reduce GHG emissions from new construction, existing buildings, and City-owned new buildings. The Toronto Green Standard (TGS), administered by the City Planning Division, is the implementation approach to new buildings. It uses the targets set out in

Toronto's Zero Emissions Buildings Framework for large buildings and the Canadian Home Builders' Association (CHBA) Net Zero Home Labelling Program to guide low-rise developments. The TGS includes four tiers of standards to achieve increasingly high energy performance. The first tier is required through the planning approval process. Tiers 2 to 4 are voluntary standards with higher level targets and financial incentives for developments that are certified to have met these targets. The standards include guidelines for air quality, energy efficiency, resilience, water resources, ecology and solid waste. At the two highest level of standards, Tiers 3 and 4, building performance levels increase.

Over 85% of Toronto's projected growth is large buildings, specifically multi-unit residential and commercial office. Adhering to the TGS requires new (large) buildings to reach near-zero emission levels by 2030. Higher targets are rolled in every four years. The specified energy efficiency requirements increase with each Tier and are certified based on different metrics depending on the building category, including targets for Total Energy Use Intensity (TEUI) and Thermal Energy Demand Intensity (TEDI). High building energy performance is shown to lower energy-related emissions and associated air pollutants. Reductions in outdoor air pollutants $PM_{2.5}$, NO_x and O_3 can reduce the incidence of cerebrovascular, respiratory, and cardiovascular illnesses, as shown in studies on the health impacts of high energy efficiency building standards (European Commission 2013; West et al. 2013; MacNaughton et al. 2018).

IMPACT: *Buildings designed and constructed according to high energy efficiency standards can lower emissions of outdoor air pollutants from fossil fuel combustion and as a result contribute to improved physical health.*

Studies have shown that the urban heat island (UHI) effect is one of the main contributing factors to heat mortality in urban centres (Laaidi et al. 2012; Taylor et al. 2015; Heaviside et al. 2016; Heaviside et al. 2017). UHIs compromise human health by increasing daytime temperatures and reducing nighttime cooling (Harlan & Ruddell 2011). Building characteristics that have shown to mitigate UHI effect by cooling ambient temperatures include reflective materials and green roofs (Giguère 2009; Lehmann 2014; Saaroni et al. 2018). To adhere to the minimum TGS requirements, a development must meet the Toronto Green Roof By-law and, for non-roof hardscapes, 50% of these hardscapes must be treated for low heat absorption. The Green Roof By-law requires roofs to be between 20-60% green, depending on the building's gross floor area. Because of these TGS requirements, it is expected that high performing new buildings in Toronto can help mitigate the UHI effect and decrease heat-related morbity and mortality.

IMPACT: *Green building practices that reduce the heat absorption of roofs and hardscape materials can help decrease the risk of heat-related illness and death by reducing urban heat.*

Building design strategies to improve energy efficiency have also been shown to improve mental health, including increased cognitive function and decreased incidence of sick building syndrome, by improving the indoor environmental quality. These improvements come from improved ventilation, as well as standards for low polluting building materials, both of which lower volatile organic compound (VOC) and carbon dioxide (CO_2) concentrations (Allen et al. 2016; Burge et al. 1987; Wargocki et al. 2002; Yousef et al. 2016). Mental health can also be improved through heightened feelings of satisfaction and comfort from occupants, which has been found to be more prevalent in green buildings than conventional buildings (Liang et al., 2014; Khoshbakht et al. 2018).

IMPACT: *New buildings built to green standards can improve cognitive function and physical health of occupants by improving indoor environmental quality.*

Urban greenery, as recommended in the TGS ecology and air quality requirements, is linked to increasing active leisure (Kaczynski et al. 2009; Schipperijn 2013; Gardsjord et al. 2014), which has been found to improve cardiovascular health and mental health and reduce obesity and cancer (Owen et al. 2010; Creatore et al. 2016). Physical health has also been predicted to improve due to the removal of air pollutants by trees (Nowak et al. 2014; Bottalico et al. 2016). Nowak et al. estimated that in 2010, trees and forests across the contiguous United States removed 17.4 million tonnes of air pollution, avoiding more than 850 premature deaths and 670,000 incidences of acute respiratory symptoms (Nowak et al. 2014). In addition to benefiting physical health, green space has also been found to contribute to a sense of community that benefits social cohesion and mental health (Lengen & Kistemann 2012; Kim & Kaplan 2014).

IMPACT: *New green spaces, developed in accordance with the Toronto Green Standard, can lead to better physical and mental health through improved air quality, increased physical activity and decreased stress.*

UNITED STATES

MacNaughton et al. (2018) found that reductions in NO_x, SO_2 and $PM_{2.5}$ as a result of energy savings from newly developed LEED-certified buildings in the United States are predicted to have averted 172-405 premature deaths, 171 hospital admissions, 11,000 asthma exacerbations, 54,000 respiratory symptoms, 21,000 lost days of work, and 16,000 lost days of school between 2000 and 2016. The decreased energy consumption is estimated to have saved 31 megatons of CO_2, 37 kilotons of SO_2, 28 kilotons of NO_x, and 0.4 kilotons of $PM_{2.5}$ (MacNaughton et al. 2018).

Image 3 © william87 - stock.adobe.com

4.3.3 District Energy System (DES) Installations

The International Energy Agency (IEA) has estimated that space heating and cooling, along with hot water, account for approximately 50% of building energy consumption globally (IEA 2011). To mitigate emissions from these sources, TransformTO is aiming for space heating and cooling to be sourced from low-carbon DES by 2050 - specifically, from 10,000 non-residential buildings and 625,000 residential buildings. Toronto modelled that achieving this target would reduce GHG emissions by 800 kilotonnes. The reduction in emissions is based on the expected decrease in building consumption of natural gas. Reduced emissions of natural gas are also expected to decrease ambient concentrations of NO_2, $PM_{2.5}$ and O_3, which can lead to improved physical health (Alvarez & Paranhos 2012).

Studies of potential health impacts of district thermal energy systems in Vancouver and China found that reductions in concentrations of outdoor air pollutants can reduce premature mortality (Petrov et al. 2017a, 2017b; Day et al. 2018). In Vancouver, with the use of a NO_2 control device, a biomass DES in a densely populated community could improve physical health by reducing $PM_{2.5}$ and NO_2 pollution (Petrov et al. 2017b). The study in China evaluated the health effects of reduced emissions of $PM_{2.5}$ precursors: primary PM, SO_2, NO_x, and NH_3, through wide-scale adoption of low-carbon

DES. China still relies largely on coal-fueled electricity, of which it is the largest consumer globally. Consequently, Toronto could not expect to see the same magnitude of health benefits from DES adoption. Nevertheless, Toronto could expect improved physical health from improved outdoor air quality. Switching to DES in Toronto would likely decrease natural gas combustion and associated air pollutants NO_x, $PM_{2.5}$ and O_3, which would be expected to decrease the risk of heart-related diseases, lung cancer, and chronic respiratory illnesses (Markandya et al. 2009; West et al. 2013; Wiser et al. 2016).

IMPACT: *Switching to low-carbon district thermal energy systems can contribute to improved outdoor air quality and reduced risk of chronic disease from reduced air pollution.*

CHINA

A study by C40 Cities (Day et al. 2018) predicted that transitioning from conventional heating to district thermal energy in China could decrease CO_2 emissions by 600 megatonnes by 2030. The study considered the health impacts related to reduced atmospheric concentrations of $PM_{2.5}$, from reduced emissions of $PM_{2.5}$ precursors: primary PM, SO_2, NO_x, and NH_3. C40 found that the reduction in air pollutants could prevent over 100,000 premature deaths annually (Day et al. 2018).

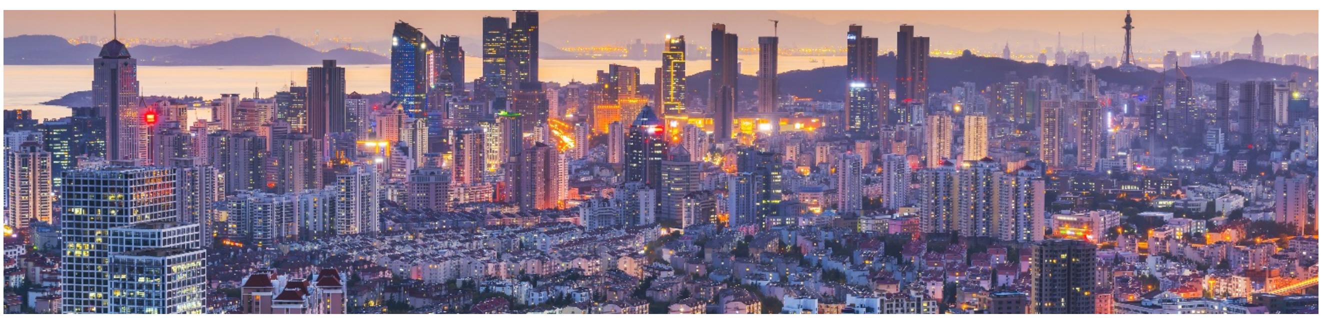


Image 4 © 昊 周 - stock.adobe.com

4.3.4 Decentralized Renewable Energy

In Canada, electric power generation is responsible for approximately one third of national GHG emissions by industry sector. However, Ontario has made significant progress in decarbonizing its energy supply by phasing out coal (ECCC 2018). Transitioning to a low-carbon electrical grid has significantly improved air quality in Toronto and has eliminated GHG emissions from coal. However, over 60% of Toronto's energy is still generated from burning natural gas (City of Toronto 2015). Under TransformTO, the City of Toronto has established the target of supplying 75% of community-wide energy through renewable or low-carbon energy generation sources by 2050.

Previous studies in the US and globally have shown that reducing fossil-fuel emissions, from both coal and natural gas, has been associated with significant health benefits by decreasing concentrations of $PM_{2.5}$, NO_x, O_3 and SO_2 (Markandya et al. 2009; West et al. 2013; Wiser et al. 2016). With Toronto's low-carbon electrical grid, increasing renewables could benefit the physical health of residents by reducing air pollutants associated with natural gas combustion: NO_2, $PM_{2.5}$ and O_3. Improved air quality has been found to decrease respiratory illnesses, cancer incidence, heart-related diseases, and, in some studies, post-neonatal mortality (Wong et al. 2004; Markandya et al. 2009; Pérez et al. 2009; Wiser et al. 2016).

IMPACT: *Decarbonizing Toronto's power supply through increased adoption of renewable energy sources can reduce energy-related air pollution and contribute to improved physical health.*

UNITED STATES

The United States "SunShot Vision" target is to supply 27% of national energy consumption through solar power by 2050, reducing coal-fired and natural gas-fired energy generation. Wiser et al. (2016) found that this goal would reduce emissions of NO_2, SO_2, and $PM_{2.5}$ by 5 million, 4 million and 600,000 tonnes, respectively. Improved outdoor air quality is predicted to prevent between 25,000 and 59,000 premature deaths from respiratory and heart-related illnesses (Wiser et al. 2016).

Image 5 © CrackerClips - stock.adobe.com

4.3.5 Active Transportation Infrastructure

A recent study conducted by C40 cities across 26 cities found that the largest (37%) contributor to $PM_{2.5}$ air pollution was fossil fuel vehicle traffic, or the exhaust of diesel and gasoline engines (C40 Cities 2018). Motor vehicle traffic is also the greatest source of air pollution emitted in Toronto (City of

Toronto 2017a), with transportation being the second greatest source of GHG emissions, accounting for approximately one third of the city's total emissions (City of Toronto 2019). To reduce traffic-related emissions, TransformTO has established a 2050 target to use low to zero-carbon energy sources for all transportation options. As part of this target, active transportation will account for 75% of trips under 5 km. TransformTO describes a future low-carbon Toronto where transport to work is distributed as 17% walking, 28% cycling, 23% taking public transit, and 32% people driving. This would amount to 50% fewer people driving than are currently.

As active transportation is the most common form of physical exercise, increasing walking and biking can be the most practical way to improve public physical health (Litman 2018). Expanding active transportation infrastructure has been found to shift the modal split. In Barcelona, it was found that a public bike sharing initiative could replace more than 28,000car trips with bike trips (Rojas-Rueda et al. 2011). In Wisconsin, adding sidewalks to all streets of Dane County is expected to increase daily walking and cycling by 0.1 miles per capita (Guo and Gandavarapu 2010). These kinds of active transportation improvements can help adults realize the recommended 150 minutes per week of physical activity (CSEP 2019). Moreover, routine physical exercise can provide significant health benefits, including reductions in premature deaths and incidence of diabetes, cancer, and heart-related illnesses (Rojas-Rueda et al. 2011; Maizlish et al. 2013; Litman 2018). Other studies find that neighbourhoods with increased multi-modal options have lower rates of overweight residents than areas with a car-centric design because there is higher prevalence of walking and cycling (Frank et al. 2004; Creatore et al. 2016; Sallis et al. 2016).

IMPACT: *Expanded active transportation infrastructure promotes walking and cycling, which can improve cardiovascular health and reduce the likelihood of premature mortality, diabetes, and cancers.*

TransformTO plans for a significant shift from driving to walking and cycling. Modelling results from multiple studies suggest that such a change in mode share will decrease ambient air concentration of $PM_{2.5}$, NO_x, SO_2 and CO (Brugge et al. 2007; Rojas-Rueda et al. 2011; Maizlish et al. 2013; Litman 2018). Improved outdoor air quality from fewer cars on the road can improve cardiovascular health and reduce incidence of asthma, bronchitis, allergic diseases, and lung cancer (Brugge et al. 2007; Chen et al. 2013; Maizlish et al. 2013).

IMPACT: *A modal shift away from fossil fuel vehicles to walking, cycling, and other green transportation options can reduce the incidence of heart-related diseases, respiratory illnesses, and cancer by decreasing concentrations of air pollutants from transportation exhaust.*

Studies have found that the overall mental wellbeing of individuals who commute using active transportation is significantly higher than those who commute by motor vehicle or public transit= (Erickson et al. 2010; Maizlish et al. 2013; Goryakin and Suhrcke 2014). Physical exercise from active transportation can also reduce the incidence of depression, cognitive decline, and dementia (Erickson et al. 2010; Maizlish et al. 2013).

IMPACT: *Expanded and improved active transportation infrastructure can lead to mental health benefits from increased physical activity.*

Based on previous research, it is anticipated that TransformTO's target to reduce vehicle traffic will have the greatest impact on residents who live in close proximity to major highways and arterial roads. Studies have found that traffic-related air pollutants (including $PM_{2.5}$, NO_x, black carbon, and CO) have the greatest health impacts on people living or spending extensive amounts of time in close proximity to roads with high volumes of vehicular traffic (Brugge et al. 2007; Karner et al. 2010; Zhang & Batterman 2013; City of Toronto 2017a). The distance from roads affected by tailpipe air pollutants varies between 115 and 570 m from the edge (Karner et al. 2010). Health impacts from pollutants include increased incidence of heart-related diseases and asthma and reduced respiratory capacity (Brugge et al. 2007; Zhang & Batterman 2013; City of Toronto 2017a). In Toronto and other major cities, the population that lives, works, and plays near major highways and arterials will experience the greatest benefits from reduced traffic and air pollutants (City of Toronto 2017a).

IMPACT: *By decreasing motor vehicle traffic and associated air pollution, increased use of active transportation infrastructure can improve the physical health of residents, particularly those near major highways and arterial roads.*

DANE COUNTY, UNITED STATES

Modelling by Guo and Gandvarapu (2010), based on the 2001 National Household Travel Survey, found that adding sidewalks to all streets of Dane County could increase daily walking and cycling by 0.1 miles per capita and reduce daily motor vehicle travel by 1.1 miles per capita. Every one-mile increase in active transportation was associated with a 12-mile decrease in car travel. In turn, increased physical exercise from reduced car travel would prevent significant weight gain in 37% of Dane County residents (Guo and Gandavarapu 2010).

Image 5 © Kayle Kaupanger on Unsplash

VANCOUVER, CANADA

The City of Vancouver, with the University of British Columbia, tracked the health impactsof active transportation infrastructure improvements to 2 km of the Comox-Helmcken Greenway corridor. For residents living within 500 metres of the Greenway, moderate physical activity increased by 16.1%, time spent sitting decreased by 8.0%, and days of poor health decreased by 9.8%after the improvements were made. The overall increase in active transportation use reduced annual CO_2 emissions by 13 tonnes (Frank & Ngo 2016).

Image 6 © Paul Krueger on Flickr

4.3.6 Public Transit Infrastructure/Investments

Air pollution in Toronto contributes to 1,300 premature deaths and over 3,500 hospitalizations annually, with vehicular traffic being the largest emitter of air pollutants in the City (City of Toronto 2017a). Expanding public transit infrastructure and increasing low-carbon transportation options can reduce the modal share of motor vehicles, which has been found to decrease outdoor air pollutants, and improve physical health (de Nazelle et al. 2011; Xia et al. 2015; Kwan et al. 2017). Tailpipe air pollutants of fossil fuel vehicles, including $PM_{2.5}$, NO_x, CO and VOCs, have been linked to cardiovascular diseases, asthma, cancers and premature deaths (Xia et al. 2015; Tétreault et al. 2018). In previous studies, ambient concentrations of $PM_{2.5}$ and its precursors NO_x and SO_2 are identified as the major health drivers related to reduced motor vehicle traffic (Xia et al. 2015; Kwan et al. 2017). Reductions in these air pollutants can improve cardiovascular and respiratory health and decrease premature mortality (Rojas-Rueda et al. 2011; Maizlish et al. 2013; Xia et al. 2015; Kwan et al. 2017).

***IMPACT**: A modal shift to public transit can improve cardiovascular and respiratory health by decreasing road traffic and tailpipe air pollutants $PM_{2.5}$, NO_x, CO and VOCs.*

Some studies have found that the greatest health benefit from public transit is increased physical exercise from commuters travelling the first and last mile of transit trips using active transportation (Kwan et al. 2017; Tétreault et al. 2018). Physical activity can reduce the incidence of premature mortality, diabetes, obesity, cancers, and heart-related illnesses (Frank et al. 2004; Rojas-Rueda et al. 2011; Maizlish et al. 2013; Creatore et al. 2016; Sallis et al. 2016; Litman 2018).

***IMPACT:** Expanding and improving access to public transit infrastructure can improve physical health of nearby residents who use active transportation to access public transit.*

Motor vehicle traffic has been identified as the primary cause of road injuries to all road users (Fuller & Morency 2013). Reductions in road traffic through shifts to public transit can reduce the risk of road traumas and fatalities and improve physical health (Xia et al. 2015; Kwan et al. 2017; Tétreault et al. 2018). Studies have also found that well-designed public transit offers safety benefits over other modes in terms of avoidance of premature death (Xia et al. 2015; Duduta et al. 2012).

***IMPACT:** Increased trips by public transit can reduce the occurrence of road traumas by decreasing road traffic.*

MONTREAL

A study conducted by Tétreault et al. (2017) for Public Health Montreal, in collaboration with multiple universities, evaluated the health impacts of eight subway stations, 13 train stations, and six light rail transit stations that are planned for the Greater Montreal Region. Frank & Ngo found that the greatest health benefit would likely arise from a 2% increase in daily walking and a 1% decrease in NO_2 outdoor air concentration. It is expected that these health drivers would avoid 2.5 DALYs per 100,000 persons annually (Tétreault et al. 2017).

Image 7 © Christian - stock.adobe.com

4.3.7 Electric Vehicles

TransformTO sets the target of adopting low- or zero-emission vehicles by 2050. Increasing the proportion of personal vehicles that are electric will be a significant step in achieving this goal. For the population who will not shift to active transportation or public transit, driving an electric vehicle (EV) can still help mitigate traffic-related emissions. In Ontario, it is estimated that switching to an EV can reduce a person's vehicle emissions between 67-95% and eliminate direct (tailpipe) emissions of $PM_{2.5}$, NO_x, CO and VOCs (Plug'n Drive 2015; Xia et al. 2015; Tétreault et al. 2018).

An increase in market penetration of EVs, coupled with decarbonization of electricity, is predicted to have substantial health benefits and equally significant local environmental benefits (Buekers et al. 2014; Malmgren 2016). Because EVs increase electricity demand, local health and environmental benefits can only be realized if local electricity generation is low-carbon. Ontario's phase-out of coal-fired electricity generation in 2014 was an essential step along this path. Reducing vehicle tailpipe emissions of $PM_{2.5}$, NO_x, CO and VOCs is expected to reduce premature deaths, cardiovascular diseases, respiratory illnesses and cancers (Rojas-Rueda et al. 2011; Maizlish et al. 2013; Xia et al. 2015; Malmgren 2016; Kwan et al. 2017). Malmgren (2016) has monetized the potential health benefits of switching to EV fueled by zero-carbon energy as $1,686 USD per driver over a typical vehicle lifespan of 10 years. These health benefits are based on the mitigation of $PM_{2.5}$ tailpipe emissions, which Malmgren associates with reduced incidence of premature death, cardiovascular and respiratory illness, cancers, and reproductive harm (Malmgren 2016).

IMPACT: *Replacing conventional vehicles with electric vehicles can benefit cardiovascular and respiratory health of people near roadways by mitigating emissions of traffic-related air pollutants $PM_{2.5}$, NOx, CO and VOCs.*

Studies in the Netherlands and Switzerland found that reduced traffic noise from increased use of EVs can lead to physical and mental health benefits (Perez et al. 2015; Tobollik et al. 2016). Noise pollution has been linked to cardiovascular mortality, cognitive impairment, mental health problems, high annoyance, and sleep disturbance (Babisch 2014; Drew et al. 2017; Miedema & Oudshoorn 2001; Miedema & Oudshoorn 2003). Although the estimated noise-related mental and physical health benefits have been small, increasing the proportion of EVs to 50% of personal vehicles in a city can reduce premature mortality from reduced exposure to traffic noise (Perez et al. 2015; Tobollik et al. 2016). Studies from Montréal (Ragletti et al. 2015) and Toronto (Drew et al. 2017) have also confirmed the negative health impacts of excessive exposure to traffic noise, which suggests that the health benefits of reduced traffic noise from adopting EVs would not be limited to European cities. The latter study, which was conducted by Toronto Public Health, also found that the negative health impacts of over-exposure to traffic noise are disproportionately borne by lower-income neighborhoods (Drew et al. 2017), which suggests that the transition to EVs may also offer health equity benefits.

IMPACT: *Increased adoption of electric vehicles can benefit mental and physical health by reducing traffic noise and associated annoyance and sleep disturbance.*

ROTTERDAM, NETHERLANDS

Tobollik et al. (2016) modelled the health impacts of a scenario in which 50% of personal vehicles in Rotterdam are electric. They found that, reduced noise would prevent annoyance of 85 people and sleep disturbance of 49 people among the city's population of 13,000. This health impact translates into a total of 1,868 years lived with disability avoided annually (Tobollik et al. 2016).

Image 8 © David.Sch - stock.adobe.com

4.3.8 Cross-cutting

Air pollution has been identified as one of the largest threats to children's health, given fetuses, infants, and children are found to be more vulnerable than adults to air pollutants (Sheffield & Landrigan 2011; Perera 2017; WHO 2018). It is estimated that 88% of the global burden of disease of climate change occurs in children under 5 years of age (Sheffield & Landrigan 2011). A review of studies by WHO found that air pollution can contribute to adverse birth outcomes, infant mortality, neurodevelopment issues, obesity, respiratory effects, ear diseases, and cancer (WHO 2018). Consequently, reducing the concentration of ambient air pollutants by increasing energy conservation, transitioning to renewable energy, and mitigating traffic-related air pollution can have substantial health benefits for children under five.

IMPACT: *Mitigating air pollutants through various GHG-reduction actions under TransformTO will have health benefits for everyone, including the youngest members of the population who bear the greatest burden of climate change.*

UNITED STATES

In the United States, it was estimated that the *U.S. Clean Air Act* reduced post-neonatal mortality, asthma hospitalizations, missed school days, and low birth weights by reducing concentrations of PM_{10}, $PM_{2.5}$, NO_2, O_3, and SO_2 (Wong et al. 2004).

Image 9 © Africa Studio - stock.adobe.com

5. Conclusions

Climate change has been described as the “biggest global health challenge of the 21st century” (Watts et al. 2018). By establishing linkages between actions to reduce greenhouse gas emissions under TransformTO and health and health equity co-benefits, the City can help convey the importance of reducing emissions and increase support for GHG-reduction actions. The quantification of health and health equity co-benefits of GHG-reduction actions is a growing field of study. No standardized coefficients exist to translate the quantified co-benefits from research in other jurisdictions to Toronto. While the co-benefits quantified through research in other jurisdictions cannot be directly applied to Toronto, universally applicable trends link GHG-reduction actions and health and health equity co-benefits. These trends can be expected to apply to similar actions taken in Toronto. These linkages, found from reviewing over 160 studies and reports through two phases of research, have been presented throughout this report.

A summary of research-supported linkages between GHG-reduction actions and health and health equity co-benefits is presented below.

Building Retrofits

1. Building energy retrofits can reduce outdoor air pollutants associated with electricity and natural gas consumption and as a result benefit physical health.
2. Building retrofits can benefit the physical and mental health of residents by improving indoor air quality and reducing dampness and exposure to noise.
3. Improvements to insulation of poorer quality homes can improve the physical and mental health of vulnerable populations and reduce energy poverty.

Toronto Green Standard

4. Buildings designed and constructed according to high energy efficiency standards can lower emissions of outdoor air pollutants from fossil fuel combustion and as a result contribute to improved physical health.
5. Green building practices that reduce the heat absorption of roofs and hardscape materials can help decrease the risk of heat-related illness and death by reducing urban heat.
6. New buildings built to green standards can improve cognitive function and physical health of occupants by improving indoor environmental quality.
7. New green spaces, developed in accordance with the Toronto Green Standard, can lead to better physical and mental health through improved air quality, increased physical activity and decreased stress.

District Energy System Installations

8. Switching to low-carbon district thermal energy systems can contribute to improved outdoor air quality and reduced risk of chronic disease from reduced air pollution.

Decentralized Renewable Energy

9. Decarbonizing Toronto's power supply through increased adoption of renewable energy sources can reduce energy-related air pollution and contribute to improved physical health.

Active Transportation Infrastructure

10. Expanded active transportation infrastructure promotes walking and cycling, which can improve cardiovascular health and reduce the likelihood of premature mortality, diabetes, and cancers.
11. A modal shift away from fossil fuel vehicles to walking, cycling, and other green transportation options can reduce the incidence of heart-related diseases, respiratory illnesses, and cancer by decreasing concentrations of air pollutants from transportation exhaust.
12. Expanded and improved active transportation infrastructure can lead to mental health benefits from increased physical activity.
13. By decreasing motor vehicle traffic and associated air pollution, increased use of active transportation infrastructure can improve the physical health of residents, particularly those near major highways and arterial roads.

Public Transit Infrastructure/Investments

14. A modal shift to public transit can improve cardiovascular and respiratory health by decreasing road traffic and tailpipe air pollutants $PM_{2.5}$, NO_x, CO and VOCs.
15. Expanding and improving access to public transit infrastructure can improve physical health of nearby residents who use active transportation to access public transit.
16. Increased trips by public transit can reduce the occurrence of road traumas by decreasing road traffic.

Electric Vehicles

17. Replacing conventional vehicles with electric vehicles can benefit cardiovascular and respiratory health of people near roadways by mitigating emissions of traffic-related air pollutants $PM_{2.5}$, NO_x, CO and VOCs.
18. Increased adoption of electric vehicles can benefit mental and physical health by reducing traffic noise and associated annoyance and sleep disturbance.

Cross-Cutting

19. Mitigating air pollutants through various GHG-reduction actions under TransformTO will have health benefits for everyone, including the youngest members of the population who bear the greatest burden of climate change.

If, at a later date, the City is interested in developing estimates of the health and health equity co-benefits of actions taken under TransformTO, it could conduct an original research study using locally sourced data.This would establish a baseline for reporting progress on health and health equity co benefits of TransformTO.

Glossary of Key Terms

This glossary provides definitions of several technical terms that are used in the literature on health co-benefits and throughout this report. Some of the terms are technical and used differently by different researchers. The definitions in this glossary represent our attempt to bring clarity to their interpretation. They are explained in greater detail, with citations provided, throughout this report and in Report 1 prepared for this project.

Burden of Disease (BoD)
A framework that quantifies the burden of premature mortality and morbidity in a population by determining how much of one or several specified health outcomes can be attributed to exposure to one or a group of specified risk factors. BoD is calculated using a summary health metric – DALY (see below) – that combines estimates of the Years of Life Lost (YLL) due to premature mortality and Years Lived with Disability (YLD).

Co-Benefits
Co-benefits are the benefits of policies implemented for various reasons at the same time, acknowledging that most policies designed to mitigate GHG emissions have other and often at least equally important rationales (e.g., related to objectives of development, sustainability, and equity) (IPCC, 2007).

Comparative Risk Assessment (CRA)
A framework that systematically evaluates how the Burden of Disease (BoD) (see above) in a population changes by shifting the population's level of exposure to a risk factor or group of risk factors toward a counterfactual exposure level. CRA quantifies changes in health using a summary health metric – DALY (see below) – to combine estimates of the Years of Life Lost (YLL) due to premature mortality and Years Lived with Disability (YLD).

Disability-Adjusted Life Year (DALY)
DALY is a summary health metric that combines mortality and morbidity and is used to measure the Burden of Disease (BoD) (see above) in a population. It is calculated as the sum of Years of Life Lost (YLL) due to premature mortality and Years Lived with Disability (YLD) for persons living with a morbidity (see below). One DALY can be thought of as one year of "healthy" life lost.

Health Equity
The concept that everyone should have a fair opportunity to attain their full health potential and that no one should be disadvantaged from achieving this potential. The concept is different than everyone having equal health, but rather describes the principle of equal access to resources needed to improve or maintain health.

Health Impact
The positive or negative effect of any factor (or a change thereof) on the health of a population. In the context of health co-benefits studies, these factors are typically related to climate change or climate mitigation activities.

Health Impact Assessment (HIA)
A framework that integrates a range of analytical methods and procedures to evaluate the potential impacts of a policy, program, or intervention on the health of a population, with a view to maximizing the positive impacts and minimizing the negative impacts.

Indoor Environmental Quality (IEQ)
A summary description of the conditions inside a building that effect occupants and residents including air quality, lighting, thermal conditions, and ergonomics.

Mental Health
A state of well-being in which an individual realizes her or his own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community.

Post-Neonatal Mortality
Infant death occurring between 28 to 364 days after birth.

Quality Adjusted Life Year (QALY)
A measure of disease burden that assigns each year of life a utility value, or quality of life (ranging from 0=death to 1=perfect health).

Sick Building Syndrome (SBS)
SBS is the occurrence of an excessive number of subjective complaints by the occupants of a building. These complaints can include headache, irritation of the eyes, nose, and throat, lethargy, inability to concentrate, objectionable odors, nausea, dizziness, and chest tightness.

Urban Heat Island Effect
This effect refers to the observed temperature difference between urban environments and the surrounding rural areas at the macro scale.

Years of Life Lost (YLL)
YLL is a duration-based health metric that measures the years of life lost due to premature mortality in a population. It is calculated as the product of the number of deaths in a population due to a particular health condition and the standard remaining life expectancy at the age of death from the

health condition for the population.

Years Lived with Disability (YLD)

YLD is a duration-based health metric that measures the productive years of life lost due to living with a morbidity in a population. It is calculated as the product of the number of incident cases for a particular health condition in a population, a disability weight of the health condition (ranging from 0=perfect health to 1=death), and the average duration (years) of the morbidity in the population.

Appendix A

Table 1: Summary of findings from 20 studies on health co-benefits of GHG-reduction actions

Building Retrofits					
Location	**GHG-Reduction Action**	**Impact**	**Co-benefit**	**Model/Experiment**	**Reference**
United Kingdom	Residential building fabric and ventilation retrofits.	- reduced heat energy demand by 30% - increase of indoor wintertime temperatures by 0.3ºC - decreased indoor sources of $PM_{2.5}$ by 53% (or 4.8 µg/m^3) - increase in exposure to $PM_{2.5}$ from outdoor sources by 4.3%	Predicted improvements over 50 years: - Modelling impacts to indoor environment on 18.99 M households predicted positive effects on net mortality and morbidity of 2,241 QALYs gained per 10,000 people over 50 years	Health Impact of Domestic Efficiency Model (HIDEEM)	Hamilton et al. 2015
United Kingdom	1) Improving insulation and ventilation control in residences 2) Switching indoor fossil fuel uses to electricity 3) Changing residents' behaviour	GHG reduction: - reduction in CO_2 emissions by 0.6 megatonnes per million people Improved indoor air quality: - decrease in household $PM_{2.5}$ concentrations by 3.0 µg/m3 Health risks: - increase mold growth by 3.1% - decreasing indoor	Estimated overall positive impact to health benefits of 850 fewer DALYs annually per million people	Model similar to WHO's Comparative Risk Assessment	Wilkinson et al. 2009

		wintertime temperature by 0.4ºC			
New Zealand	Retrofitted insulation in single-story, detached households	- 23% less energy consumed - 0.6ºC increase in average bedroom temperature - 3.8% less relative humidity	- 44% less nights-in-hospital - fewer days off school and work - reduced incidence of cold, flu, and respiratory illnesses	Community-based randomized trial with 1,400 houses	Howden-Chapman et al. 2004
Canada	Energy-saving lighting retrofit in commercial buildings	Satisfaction with lighting: - 14% more office workers more comfortable with lighting intervention	- predicted benefits to office occupant mental health and wellbeing - higher environmental performance satisfaction and job satisfaction - greater comfort among office workers, more pleasant moods	Occupant survey	Veitch et al. 2010

Toronto Green Standard					
Location	**GHG-Reduction Action**	**Impact**	**Co-benefit**	**Model/Experiment**	**Reference**
United States	LEED-Certified Buildings	GHG reduction: - 31 MT less CO_2 Improved outdoor air quality from 2000-2016: - 37 kt less SO_2 - 28 kt less NO_x - 0.4 kt less $PM_{2.5}$	Predicted to have prevented from 2000-2016: - 172-405 premature deaths - 171 hospital admissions - 11,000 asthma exacerbations - 54,000 respiratory symptoms - 21,000 lost days of work - 16,000 lost days of school	Harvard's Co-Benefits of the Built Environment (Co-BE) calculator	MacNaughton et al. 2018
United States	Green commercial buildings	Improved indoor air quality: - outdoor air ventilation doubled to 40 cfm/person - average CO_2 concentration decreased by 448 ppm - average VOC concentration decreased by 651 µg/m3	Predicted mental health improvements: - cognitive scores 101% greater	Natural experiment	Allen et al. 2016

District Energy Systems Installations					
Location	**GHG-Reduction Action**	**Impact**	**Co-benefit**	**Model/Experiment**	**Reference**
China	District heating and cooling networks	GHG reductions: - 600 $MtCO_{2e}$ less GHG emissions through district heating network - 200 MtCO2e less annual emissions through district cooling network	Predicted to Prevent Annually: - 100,000 premature deaths through implementation of district heating network - 15,000 premature deaths through implementation of district cooling network - incidence of sick-building syndrome (not quantified)	Study-specific methods	Day et al. 2018
Vancouver, Canada	Biomass district heating systems	GHG reduction: - 55,585 t less CO_2 Improved outdoor air quality: - 287 t less $PM_{2.5}$ - 62.3 t increase in NO_X	Annual prediction: - 213 more DALYs with NO_X control device - 297 less DALYs	Intake Fraction (iF) and health-related impact score (IS)	Petrov et al. 2017a (Part I), and Petrov et al. 2017b (Part II)

Decentralized Renewable Energy					
Location	**GHG-Reduction Action**	**Impact**	**Co-benefit**	**Model/Experiment**	**Reference**
United States	27% of national energy supplied by solar power	GHG reduction: - 8 B t (10%) less CO_2 Improved outdoor air quality: - 3.8 M t less SO_2 - 5.1 M t less NO_x - 600,000 t less $PM_{2.5}$	Predicted to Prevent Annually: - 25,000-59,000 premature deaths - 30,800 hospital admissions - 2.5 M lost days of work - 2.5 M lost days of school	Air Pollution Emission Experiments and Policy (AP2) analysis model and EPA's marginal benefit methodology	Wiser et al. 2016
European Union	Policies to reduce PM2.5 through renewable energy use	GHG reduction: - 1,577 M t less CO_2 Improved outdoor air quality: - 0.3 μg/m³ less $PM_{2.5}$	Predicted to Prevent Annually (per 1 M people): - 104 YLL - 10 premature deaths - $2 USD per 1 t CO_2	Adaptation of WHO's Comparative Risk Assessment	Markandya et al. 2009
Active Transportation Infrastructure					
Location	**GHG-Reduction Action**	**Impact**	**Co-benefit**	**Model/Experiment**	**Reference**
United States	Transportation strategies to reduce GHG emissions	Two scenarios: *Conservative*: - 195,300 t less CO_2 - walking and biking increase by 5.3 minutes per capita (1.41 miles) *Aggressive*: - 4.04 M t less CO_2 - walking and biking increase by 10 minutes per capita (2.57 miles)	Predicted to prevent annually: - 29,503 DALYs (conservative scenario) - 38,971 DALYs (aggressive scenario)	Integrated Transport and Health Impacts model (ITHIM)	Maizlish et al. 2013

Barcelona, Spain	Bike sharing infrastructure	- reduced annual emissions by 9,026 t of CO_2 - increased physical activity	Predicted to: - prevent 12.46 premature deaths annually per study population - increase 0.16 premature deaths annually due to inhalation of air pollutants and road traffic injuries	Health Impact Assessment method	Rojas-Rueda et al. 2011
Ontario, Canada	Neighbourhood walkability	- 5 times more trips walking or biking and 3 times more trips by public transit (most walkable neighbourhood compared to least walkable)	Improved neighbourhood walkability likely contributed to: - 10% less prevalence of bariatric health problems - 15 % less incidence of diabetes	Times series analysis from 2000-2012	Creatore et al. 2016
Vancouver, Canada	Active transportation infrastructure improvement projects on 2 km corridor	- 16.1% more moderate physical activity - 8% less sitting	- 9.8% fewer days reported of poor physical and mental health	Natural experiment using neighbourhood surveys and trip diaries	Frank and Ngo 2016
Public Transit Infrastructure/Investments					
Location	**GHG-Reduction Action**	**Impact**	**Co-benefit**	**Model/Experiment**	**Reference**
Montreal, Canada	Transit infrastructure expansion (19 transit stations)	Improved air quality and shift in daily transportation: - 1% less NO_2 - 2% more daily walking (32,127 km) - 1% less daily cycling (5,522 km)	Predicted to Prevent Annually: - 2.5 DALYs per 100,000 people	Combination of databases and models	Tétreault et al. 2017

Adelaide, Australia	Cycling and public transit infrastructure to reduce motor vehicle travel by 40% or 13.4 M km/day	954,503 t less CO_2 Increased physical activity, reduced road injuries and improved outdoor air quality: - 0.39 µg/m^3 less $PM_{2.5}$	Predicted to reduce annually (in population of 1.4 million): - deaths by 542 - overall DALYs by 7,674	Comparative health risk assessment	Xia et al. 2014
Greater Kuala Lumpur, Malaysia	103 km of mass rapid transit line	242,210 t less CO_2 annually Improved air quality and shift in daily transportation: - 67.8 kg less $PM_{2.5}$ annually - 4.2 M km decreased in vehicle trips	Predicted to prevent annually: - 104 DALYs from reduced $PM_{2.5}$ (for population of 1.2 M) - 6,300 DALYs from reduced traffic injuries (for population of 442,000) - 3,200 DALYs from increased physical activity (for population of 442,000)	Adaptation of Comparative Health Risk Assessment used in Integrated Transport and Health Impacts model, and analysis of self-reported trip surveys	Kwan et al. 2017

Electric Vehicles					
Location	**GHG-Reduction Action**	**Impact**	**Co-benefit**	**Model/Experiment**	**Reference**
Rotterdam, Netherlands	Two scenarios: A 10% reduction in private vehicular travel (1) and 50% of private vehicles being electric (2)	Negligible impacts to outdoor air quality, but reduced exposure to noise: - reduced annoyance - reduced sleep disturbance	Predicted to prevent annually in population of 12,946: - 1,879 YLDs (1) - 1,869 YLDs (2)	Health Impact Assessment method	Tobollik et al. 2016
Basel, Switzerland	Combined scenario: A 10% reduction in private vehicular travel and 50% of private vehicles being electric	Improved air quality: - 5.69 µg/m^3 less $PM_{2.5}$ - 1.08 µg/m^3 less elemental carbon - 7% increase in biking and walking Reduced exposure to noise: - 1.39 dBA less Lden - 1.28 dBA less Lnight	Predicted to prevent (in population of 1,000): - 309 DALYs from reduced air pollution - 0.71 DALYs from noise reduction - 0.06 DALYs from increased physical activity	Health Impact Assessment method	Perez et al. 2015

References

Allen, T. (2005a). Private sector housing improvement in the UK and the chronically ill: implications for collaborative working. *Housing Studies,* 20(1):63e80.

Allen, T. (2005b). Evaluation of the housing for healthier hearts project April 2003-March. Bradford: University of Bradford; 2005.

Alvarez, R. and Paranhos, E. (2012). Air pollution issues associated with natural gas and oil operations. *Air & Waste Management Association.* Retrieved from: https://www.edf.org/sites/default/files/AWMA-EM-airPollutionFromOilAndGas.pdf.

Babisch, W. (2014). Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis. Noise and Health, 16(68), 1. doi:10.4103/1463-1741.127847.

Barton, A., Basham M., Foy C., Buckingham, K., and Somerville, M., on behalf of the Torbay Healthy Housing Group. (2007). The Watcombe Housing Study: the short term effect of improving housing conditions on the health of residents. *Journal of Epidemiol Community Health,* 61(9):771e7.

Becchio, C., Bottero, M. C., Corgnati, S. P., & Dell'Anna, F. (2018). Evaluating Health Benefits of Urban Energy Retrofitting: An Application for the City of Turin. *Green Energy and Technology*, 281–304. doi:10.1007/978-3-319-75774-2_20

Bond, L., Kearns, A., Mason, P., Tannahill, C., Egan, M., & Whitely E. (2012) Exploring relationships between housing, neighbourhoods and mental wellbeing for residents of deprived areas. *BMC Public Health,* 48 Retrieved from: http://www.biomedicalcentral.com/1471-2458/12/48

Bonnefoy, X. (2007). Inadequate housing and health: An overview. *International Journal of Environment and Pollution*, 30(3/4), 411. doi: 10.1504/IJEP.2007.014819

Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., & Travaglini, D. (2016). Air Pollution Removal by Green Infrastructures and Urban Forests in the City of Florence. Agriculture and Agricultural Science Procedia, 8, 243–251. doi:10.1016/j.aaspro.2016.02.099

Braubach, M., Heinen, D., & Dame, J. (2008) Preliminary results of the WHO Frankfurt housing intervention project. Copenhagen: World Health Organisation.

Braubach, M., Egorov, A., Mudu, P., Wolf, T., Ward Thompson, C., & Martuzzi, M. (2017). Effects of Urban Green Space on Environmental Health, Equity and Resilience. *Nature-Based Solutions to Climate Change Adaptation in Urban Areas,* 187–205. doi:10.1007/978-3-319-56091-5_11.

Brugge, D., Durant, J. L., & Rioux, C. (2007). Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks. *Environmental Health,* 6(1). doi:10.1186/1476-069x-6-23

Buekers, J., Van Holderbeke, M., Bierkens, J., & Int Panis, L. (2014). Health and environmental benefits related to electric vehicle introduction in EU countries. Transportation Research Part D: Transport and Environment, 33, 26–38. doi:10.1016/j.trd.2014.09.002.

Burget, A., Hedge, A., Wilson, S., Bass, J. H., & Robertson, A. (1987). Sick Building Syndrome: a study of 4373 office workers. *Annals of Occupational Hygiene, 31*, No. 4A pp 493-504.

C40 Cities (2018). Toward a Healthier World: Connecting the dots between Environmental Health & Public Health. *C40 Cities.* Retrieved from: https://c40-production-images.s3.amazonaws.com/other_uploads/images/2022_TOWARD_A_HEALTHIER_WORLD.original.pdf?1543934003.

Chen, H., Goldberg, M. S., Burnett, R. T., Jerrett, M., Wheeler, A. J., & Villeneuve, P. J. (2013). Long-term exposure to traffic-related air pollution and cardiovascular mortality. *Epidemiology, 24(1)*, 35–43.

City of Toronto (2015). Toronto's 2013 Greenhouse Gas Inventory. PE9.4 Corrected Report. Retrieved from: https://www.toronto.ca/legdocs/mmis/2016/pe/bgrd/backgroundfile-87697.pdf.

City of Toronto (2017a). Reducing Health Risks from Traffic-Related Air Pollution (TRAP) in Toronto. *Revised 2017.HL22.3*. Retrieved from: https://www.toronto.ca/legdocs/mmis/2017/hl/bgrd/backgroundfile-108179.pdf.

City of Toronto (2017b). TransformTO: Climate Action for a Healthy, Equitable and Prosperous Toronto - Report #2 - The Pathway to a Low Carbon Future. 2017.*PE19.4*. Retrieved from: https://www.toronto.ca/wp-content/uploads/2017/10/99b9-TransformTO-Climate-Action-for-a-Healthy-Equitable-and-Prosperous-Toronto-Report-2-The-Pathway-to-a-Low-Carbon-Future-Staff-Report-April-2017.pdf.

City of Toronto (2019). Toronto's 2016 Greenhouse Gas Emissions Inventory. Retrieved from: https://www.toronto.ca/services-payments/water-environment/environmentally-friendly-city-initiatives/transformto/torontos-greenhouse-gas-inventory

Creatore, M. I., Glazier, R. H., Moineddin, R., Fazli, G. S., Johns, A., Gozdrya, P., Matheson, F. I., Kaufman-Shriqui, V., Rosella., L. C., Manuel, D. G., & Booth, G.L. (2016). Association of neighborhood walkability with change in overweight, obesity and diabetes JAMA (20), 2211–2220.

CSEP (2019). Canadian 24-Hour Movement Guidelines. Canadian Society for Exercise Physiology. Retrieved from: https://csepguidelines.ca/

Day, T., Gonzales-Zuñiga, S., Höhne, N., Fekete, H., Steri, S., Hans, F., Warembourg, A., Anica, A., van Breevoort, P. (2018). *Opportunity 2030: Benefits of Climate Action in Cities - Quantifying the benefits of city-level measures in buildings, transport and energy supply*. Berlin, HR: New Climate Institute.

de Nazelle, A., Nieuwenhuijsen, M.J., Anto, J.M., Brauer, M., Briggs, D., BraunFahrlander, C., et al. (2011). Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. *Environment International, 37,* 766–777.

Drew, K., Macfarlane, R., Oiamo, T., Mullaly, M., Stefanova, D., & Campbell, M. (2017). *How Loud is Too Loud? Health Impacts of Environmental Noise*. Toronto, ON: Toronto Public Health.

Dudata, N., Adriazola, C., Wass, C., Hidalgo, D., & Lindau, L. A. (2012). Traffic Safety on Bus Corridors. *EMBARQ*. Retrieved from: http://www.embarq.org/sites/default/files/EMB2012_Traffic_Safety_on_Bus_Corridors_Pilot_Version.pdf.

Environment and Climate Change Canada (ECC). (2018). Overview of 2016 Reported Emissions. Government of Canada. Retrieved from: http://publications.gc.ca/collections/collection_2018/eccc/En81-6-1-2016-eng.pdf.

Environmental Commissioner of Ontario (ECO) (2018). Making Connection Straight Talk About Electricity in Ontario. *Environmental Commissioner of Ontario.* Retrieved from: http://docs.assets.eco.on.ca/reports/energy/2018/Making-Connections.pdf.

Erickson, K. I., Raji, C. A., Lopez, O. L., Becker, J. T., Rosano, C., Newman, A. B., Gagh, H. M., Thompson, P. M., Ho, A.j., & Kuller, L. H. (2010). Physical activity predicts gray matter volume in late adulthood: The Cardiovascular Health Study. Neurology, 75(16), 1415–1422. doi:10.1212/wnl.0b013e3181f88359

European Commission. (2003). External costs: Research results on socio environmental damages due to electricity and transport, Brussels.

Frank, L. D. & Ngo, V. D. (2016). Study of Travel, Health, and Activity Patterns Before and After the Redesign of the Comox-Helmcken Greenway Corridor, Final Report (Phase 2). Vancouver, BC: City of Vancouver, Active Transportation Branch.

Frank, L. D., Andresen, M. A., & Schmid, T. L. (2004). Obesity relationships with community design, physical activity, and time spent in cars. American Journal of Preventive Medicine, 27(2), 87–96. doi:10.1016/j.amepre.2004.04.011

Fuller, D., & Morency, P., (2013). A population approach to transportation planning: reducing exposure to motor-vehicles. *Journal of Environmental and Public Health, 2013*, 916460.

Gardsjord, H. S., Tveit, M. S., & Nordh, H. (2013). Promoting Youth's Physical Activity through Park Design: Linking Theory and Practice in a Public Health Perspective. Landscape Research, 39(1), 70–81. doi:10.1080/01426397.2013.793764

Giguère, M. (2009). Literature Review of Urban Heat Island Mitigation Strategies. Institut national de santé publique Québec. Retrieved from: https://www.inspq.qc.ca/pdf/publications/1513_UrbanHeatIslandMitigationStrategies.pdf.

Gao, J., Kovats, S., Vardoulakis, S., Wilkinson, P., Woodward, A., Li, J., & Liu, Q. (2018). Public health co-benefits of greenhouse gas emissions reduction: A systematic review. *Science of the Total Environment, 627,* 388-402. doi:10.1016/j.scitotenv.2018.01.193

Guo, J. Y., & Gandavarapu, S. (2010). An economic evaluation of health-promotive built environment changes. *Preventive Medicine, 50,* S44–S49. doi:10.1016/j.ypmed.2009.08.019

Harlan, S. L., & Ruddell, D. M. (2011). Climate change and health in cities: Impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. Current Opinion in *Environmental Sustainability, 3(3),* 126–134. https://doi.org/10.1016/j.cosust.2011.01.001.

Hamilton, I., Milner, J., Chalabi, Z., Das, P., Jones, B., Shrubsole, C., Davies, M., & Wilkinson, P. (2015). Health effects of home energy efficiency interventions in England: a modelling study. *BMJ Open*, *5*: e007298.

Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The Urban Heat Island: Implications for Health in a Changing Environment. Current Environmental Health Reports, 4(3), 296–305. doi:10.1007/s40572-017-0150-3.

Heaviside C, Vardoulakis S, Cai X-MM. (2016). Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. *Environmental Health,* 15:49–59

Howden-Chapman, P., Matheson, A., Crane, J., Viggers, H., Cunningham, M., Blakely, T., O'Dea, D., Cunningham, C., Woodward, A., Saville-Smith, K., Baker, M., Waipara, N. (2004). Retrofitting houses with insulation to reduce health inequities: Aims and methods of a clustered, randomised community-based trial. *Social Science & Medicine*, *61* (12), 2600-2610.

IEA. (2011). Technology Roadmap - Energy-Efficient Buildings - Heating and Cooling Equipment. Retrieved from: https://webstore.iea.org/technology-roadmap-energy-efficient-buildings-heating-and-cooling-equipment.

Isfeld-Kiely, H. & Balakumar, S. (2015). *Framing the Burden: Towards a new framework for measuring burden of disease in Canada*. Winnipeg, MB: National Collaborating Centre for Infectious Diseases.

Kaczynski, A. T., Potwarka, L. R., Smale, B. J. A., & Havitz, M. E. (2009). Association of Parkland Proximity with Neighborhood and Park-based Physical Activity: Variations by Gender and Age. Leisure Sciences, 31(2), 174–191. doi:10.1080/01490400802686045.

Karner, A. A., Eisinger, D. S., & Niemeier, D. A. (2010). Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data*. Environmental Science & Technology, 44(14),* 5334–5344. doi:10.1021/es100008x.

Khoshbakht, M., Gou, Z., Xie, X., He, B., & Darko, A. (2018). Green Building Occupant Satisfaction: Evidence from the Australian Higher Education Sector. Sustainability, 10(8), 2890. doi:10.3390/su10082890

Kim J, Kaplan R (2004) Physical and psychological factors in sense of community: new urbanist kentlands and nearby orchard village. *Environment & Behaviour,* 36:313–340.

Kwan, S. C., Tainio, M., Woodcock, J., Sutan, R., & Hashim, J. H. (2017). The carbon savings and health co-benefits from the introduction of mass rapid transit system in Greater Kuala Lumpur, Malaysia. *Journal of Transport & Health, 6*, 187-200.

Lehmann, S. (2014). Low carbon districts: Mitigating the urban heat island with green roof infrastructure. City, Culture and Society, 5(1), 1–8. doi:10.1016/j.ccs.2014.02.002.

Lengen C, Kistemann T (2012) Sense of place and place identity: review of neuroscientific evidence. *Health Place,* 18(5):1162–1171

Liang, H.-H., Chen, C.-P., Hwang, R.-L., Shih, W.-M., Lo, S.-C., & Liao, H.-Y. (2014). Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan. Building and Environment, 72, 232–242. doi:10.1016/j.buildenv.2013.11.007.

Laaidi K, Zeghnoun A, Dousset B, Bretin P, Vandentorren S, Giraudet E, et al. (2012) The impact of heat islands on mortality in Paris during the August 2003 heat wave. *Environmental Health Perspectives*, 120:254–9

Liddell, C., & Guiney, C. (2015). Living in a cold and damp home: Frameworks for understanding impacts on mental well-being. *Public Health*, 129(3), 191–199.

Liddell, C., & Morris, C. (2010). Fuel poverty and human health: A review of recent evidence. *Energy Policy*, 38(6), 2987–2997. https://doi.org/10.1016/j.enpol.2010.01.037.

Litman, T. (2018). Evaluating Active Transport Benefits and Costs. *Victoria Transport Policy Institute.* Retrieved from: http://www.vtpi.org/nmt-tdm.pdf.

Lopez, A. D. (2005). The Evaluation of the Global Buden of Disease framework for disease, injury and risk factor quantification: developing the evidence base for national, regional and global public health action. Globalization and Health, 1 (5), 1-8.

MacNaughton, P., Cao X., Buonocore J., Cedeno-Laurent J., Spengler, Bernstein A., & Allen J. (2018). Energy savings, emission reductions, and health co-benefits of the green building movement. *Journal of Exposure Science & Environmental Epidemiology*, *28*, 307–318.

Maizlish, N., Woodcock, J., Co, S., Ostro, B., Fanai, A., & Fairley, D. (2013). Health cobenefits and transportation-related reductions in greenhouse gas emissions in the San Francisco Bay Area. *American Journal of Public Health*, *103* (4), 703-709.

Malmgren, I. (2016). Quantifying the Societal Benefits of Electric Vehicles. World Electric Vehicle Journal, 8(4), 996–1007. doi:10.3390/wevj8040996.

Markandya, A., Armstrong, B., Hales, S., Chiabai, A., Criqui, P., Mima, S., Tonne, C., & Wilkinson, P. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: low-carbon electricity generation. The Lancet, 374, 2006-2015.

Miedema, H. M. E., & Oudshoorn, C. G. M. (2001). Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals. *Environmental Health Perspectives, 109(4),* 409. doi:10.2307/3454901.

Miedema, H.M., Passchier-Vermeer, W., Vos, H., 2003. Elements for a position paper on night-time transportation noise and sleep disturbance. *TNO (Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek)*. Retrieved from: https://www.environmental-expert.com/Files/0/articles/2792/noisesleepdisturbance.pdf.

Murray, C. & Lopez, A. (1999). On the comparable quantification of health risks: lessons from the Global Burden of Disease Study. *Epidemiology*, *10*, 594-605.

Nemet, G. F., Holloway, T., & Meier, P. (2010). Implications of incorporating air-quality co-benefits into climate change policymaking. Environmental Research Letters, 5(1), 014007. doi:10.1088/1748-9326/5/1/014007

Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. Environmental Pollution, 193, 119–129. doi:10.1016/j.envpol.2014.05.028

Perera, F. (2017). Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist. *International Journal of Environmental Research and Public Health, 15(1),* 16. doi:10.3390/ijerph15010016.

Pérez, L., Sunyer, J., & Künzli, N. (2009). Estimating the health and economic benefits associated with reducing air pollution in the Barcelona metropolitan area (Spain). *Gaceta Sanitaria*, 23(4), 287–294. doi:10.1016/j.gaceta.2008.07.002.

Perez, L., Trüeb, S., Cowie, H., Keuken, M. P., Mudu, P., Ragettlie, M. S., Sarigiannis, D. A., Tobolik, M., Tuomisto, J., Vienneau, D., Sabel, C., & Künzli, N. (2015). Transport-related measures to mitigate climate change in Basel, Switzerland: A health-effectiveness comparison study. *Environment International, 85*, 111-119.

Petrov, O., Xiaotaoo, B., & Lau, A. (2015a). Impact assessment of bio-mass district heating systems in densely populated communities. Part I: Dynamic intake fraction methodology. *Atmospheric Environment, 115*, 70-78.

Petrov, O., Xiaotaoo, B., & Lau, A. (2015b). Impact assessment of bio-mass district heating systems in densely populated communities. Part II: Would the replacement of fossil fuels improve ambient air quality and human health? *Atmospheric Environment, 161*, 191-199.

Platt S, Mitchell R, Petticrew M, Walker J, Hopton J, Martin C. (2007). The Scottish Executive Central Heating Programme: assessing impacts on health. Research Findings 239. Edinburgh: Scottish Executive: Social Research Development Department.

Plug'n Drive (2015). Electric Vehicles Reducing Ontario's Greenhouse Gas Emissions. Retrieved from: http://www.plugndrive.ca/wp-content/uploads/2017/07/Electric-Vehicles-Reducing-Ontarios-Greenhouse-Gas-Emissions-A-Plugn-Drive-Report.pdf.

Ragettli, M., Goudreau, S., Plante, C., Perron, S., Fournier, M., & Smargiassi, A. (2015). Annoyance from road traffic, trains, airplanes and from total environmental noise levels. *International Journal of Environmental Research and Public Health, 13 (1)*, 90.

Rojas-Rueda, D., de Nazelle, A., Tainio, M., & Nieuwenhuijsen, M. J. (2011). The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *The BMJ, 343*, d4521.

Saaroni, H., Amorim, J. H., Hiemstra, J. A., & Pearlmutter, D. (2018). Urban Green Infrastructure as a tool for urban heat mitigation: Survey of research methodologies and findings across different climatic regions. Urban Climate, 24, 94–110. doi:10.1016/j.uclim.2018.02.001

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., … Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. The Lancet, 387(10034), 2207–2217. doi:10.1016/s0140-6736(15)01284-2.

Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. *Renewable and Sustainable Energy Reviews*, 60, 1654–1677. doi:10.1016/j.rser.2016.03.028.

Sheffield, P. E., & Landrigan P. J. (2011). Global Climate Change and Children's Health: Threats and Strategies for Prevention. *Environmental Health Perspectives,* 119(3), 291-298.

Shortt, N. and Rugkasa, J. (2007). “The walls were so damp and cold” fuel poverty and ill health in Northern Ireland: results from a housing intervention. *Health Place Environ Justice Popul Health Crit Theory* GIS,13(1):99e110.

Schipperijn, J., Bentsen, P., Troelsen, J., Toftager, M., & Stigsdotter, U. K. (2013). Associations between physical activity and characteristics of urban green space. Urban Forestry & Urban Greening, 12(1), 109–116. doi:10.1016/j.ufug.2012.12.002

SSG (2016). Modelling Toronto’s Low Carbon Future Technical Paper #1: BAP Results. *City of Toronto*. Retrieved from: https://www.toronto.ca/wp-content/uploads/2017/10/970e-TransformTO-Business-As-Planned-Report-November-2016.pdf.

Steenland, K. & Armstrong, B. (2006). An Overview of Methods for Calculating the Burden of Disease Due to Specific Risk Factors. *Epidemiology*, *17*, 512-519.

Taylor J, Wilkinson P, Davies M, Armstrong B, Chalabi Z, Mavrogianni A, et al. (2015) Mapping the effects of urban heat island,
housing, and age on excess heat-related mortality in London. Urban Clim, 14:517–28.

Tétreault, L., Eluru, N., Hatzopoulou, M., Morency, P., Plante, C., Morency, C., Reynaud, F., Shekarrizfard, M., Shamsunnahar, Y., Imani, A. F., Drouin, L., Pelletier, A., Goudreau, S., Tessier, F., Gauvin, L., & Smargiassi, A. (2018). Estimating the health benefits of planned public transit investments in Montreal. *Environmental Research*, *160*, 412-419.

Tobollik, M., Keuken, M., Sabel, C., Cowie, H., Tuomisto, J., Sarigiannis, D., Künzli, N., Perez, L., & Mudu, P. (2016). Health impact assessment of transport policies in Rotterdam: Decrease of total traffic and increase of electric car use. *Environmental Research*, *146*, 350-358.

Toronto Public Health (2014). Path to Healthier Air: Toronto Air Pollution Burden of Illness Update. Technical Report. Retrieved from: https://www.toronto.ca/wp-content/uploads/2017/11/9190-tph-Air-Pollution-Burden-of-Illness-2014.pdf

Veitch, J. A., Newshawm, G. R., Jones, C. C., Arsenault, C. D. and Mancini, S. (2010) High-quality lighting: energy-efficiency that enhances employee well-being. National Research Council Canada.

Retrieved from: https://nrc-publications.canada.ca/eng/view/accepted/?id=53f056ca-7b54-4ca3-82c1-7295d97bfaba.

Wargocki, P., Sundell, J., Bischof, W., Brundrett, G., Fanger, P. O., Gyntelberg, F., … Wouters, P. (2002). Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN). Indoor Air, 12(2), 113–128. doi:10.1034/j.1600-0668.2002.01145.

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., & Costello, A. (2018). The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. The Lancet, 392(10163), 2497-2514. doi: https://doi.org/10.1016/S0140-6736(18)32594-7.

West, J. J., Smith, S. J., Silva, R. A., Naik, V., Zhang, Y., Adelman, Z., & Lamarque, J.-F. (2013). Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Climate Change, 3(10),* 885–889. doi:10.1038/nclimate2009.

Wilkinson, P., Smith, K.R., Davies M., Adair, H., Armstrong, B., Barrett, M., Bruce, N., Haines, A., Hamilton, I., Oreszczyn, T., Ridley, I., Tonne, C., & Chalabi, Z. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. *Lancet*, *374* (9705),1917-1929.

Wiser, R., Millstein, D., Mai, T., Macnick, J., Carpenter, A., Cohen, S., Cole, W., Frew, B., & Heath, G. (2016). The environmental and public health benefits of achieving high penetrations of solar energy in the United States. *Energy, 113*, 472-486.

Wong, E. Y., Gohlke, J., Griffith, W. C., Farrow, S., and Faustman, E. M. (2004). Assessing the Health Benefits of Air Pollution Reduction for Children. *Environmental Health Perspectives, 112,* 226-232.

World Health Organization (WHO) (2018). Air Pollution and Child Health Prescribing Clean Air (Advance Copy). *World Health Organization*. Retrieved from: https://www.who.int/ceh/publications/Advance-copy-Oct24_18150_Air-Pollution-and-Child-Health-merged-compressed.pdf.

Xia, T., Nitschke, M., Zhang, Y., Shah, P., Crabb, S., & Hansen, A. (2014). Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. *Environmental International, 74*, 281-290.

Yousef, A., Arif, M., Katafygiotou, M., Mazroei, A., Kaushik, A., & Elsarrag, E. (2016). Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. International Journal of Sustainable Built Environment, 5(1), 1–11. doi:10.1016/j.ijsbe.2016.03.006.

Yu, H. & Stuart, A. L. (2017). Impacts of compact growth and electric vehicles on future air quality and urban exposures may be mixed. *Science of the Total Environment*, *576*, 148-158.

Zaharna, M., & Guilleminault, C. (2010). Sleep, noise and health: review. *Noise Health*, 12(47), 64–69. http://doi.org/NoiseHealth_2010_12_47_64_63205[pii]\r10.4103/1463-1741.63205.

Zhang, K., & Batterman, S. (2013). Air pollution and health risks due to vehicle traffic. *Science of The Total Environment,* 450-451, 307–316. doi:10.1016/j.scitotenv.2013.01.07.