Health Benefits of a Low-Carbon Future

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Executive summary

Purpose

In 2007, the City of Toronto adopted the target of reducing greenhouse gas (GHG) emissions across Toronto by 80% by the year 2050, relative to 1990 levels.

The purpose of the report is to assist Toronto Public Health to better understand the health benefits, and any negative health impacts (harms), of GHG-reduction actions that could be taken to in Toronto.

This report also provides input to TransformTO, a project led by the City of Toronto Environment and Energy Division and the Toronto Atmospheric Fund. The goal of TransformTO is to identify a path that will lead Toronto to a low-carbon future, while maximizing health, equity and prosperity.

This report provides information on health aspects of GHG-reduction actions, based on a review of the literature, and is intended to help identify and communicate the benefits of achieving the City's 2050 GHG-reduction target.

Scope and methods

The approach to the Health Benefits of a Low-Carbon Future project began with consideration of the City's inventory of greenhouse gases – which identifies where GHGs are released in Toronto – and macro-scale assessments of reduction opportunities and their health significance.

From there it focused on the major sectors identified as important to GHGs and health, GHG-reduction opportunities associated with each sector, and health benefits or harms that might be anticipated from those opportunities. The sectors considered are:

- Transportation;
- Buildings (including energy);

- Urban form (though not addressed specifically in the inventory, urban form helps shape transportation and buildings);
- Food systems (also not identified in the inventory, but identified in the macro-scale assessments as significant); and
- Waste systems.

The project is focused on the GHG-reduction initiatives, and does not attempt to consider health impacts associated with climate change itself, or adaptation measures. Further, the focus is primarily on actions that would result in GHG emission reductions, not the measures that would encourage these actions to be implemented.

Modeling specific health impacts of the initiatives was beyond the scope of the project, but we did consider methods to assess health impacts (see Appendix A).

In identifying literature to review, we drew on macro assessments of health impacts, the knowledge of the project team, and searches of general and academic literature. Where possible we identified studies that were specific to Toronto, Ontario or Canada, or were related to jurisdictions with somewhat similar climates, economies and populations.

We benefited from comments on draft materials provided by a project advisory group consisting of representatives from various City of Toronto divisions and agencies, and representatives of health-focused organizations in Toronto.

Major assumptions

Although we recognize that some significant and transformational changes will be required to meet Toronto's GHG-reduction target, we assumed that those targets would be met by existing or emerging technologies, not radical breakthroughs, and without dramatic changes in the lifestyles of Torontonians.

We were not designing the initiatives to be adopted, but assumed that GHG-reduction initiatives in Toronto will primarily be consistent with those proposed or adopted in other jurisdictions with similar targets.

Status of data

An important starting point for any assessment of opportunities in Toronto is the city's GHG inventory. Toronto's GHG inventory points to the progress that has already been made, the challenge remaining to get to the 2050 target, and where the greatest reductions must be made. The inventory has some acknowledged and explicit limitations: the City is working on updating transportation emissions which have not been updated since 2008; and consistent with best practices for cities, the inventory excludes most indirect, non-electricity generation related emissions that occur outside the city's boundaries, but result from producing the products and foods used in Toronto ("scope 3" sources). Also, given that GHG impacts – unlike health impacts – are primarily global, the inventory also lacks information on the geographic distribution of emissions.

Historically, emissions of nitrogen oxides were estimated in the inventory as a surrogate for overall air quality related emissions, but those estimates are not included in the most recent update of the inventory.

Health benefits of initiatives to reduce GHG emissions are dependent on a number of highly local issues, including electricity generation mix, population characteristics and distribution, climatic conditions and the specific form of the urban area – all things that vary from city to city, and neighbourhood to neighbourhood. Conclusions – especially quantitative conclusions – are based on highly specific, local data. This means that care must be taken in extrapolating from other cities or from Toronto projects to Toronto as a whole.

In general, the literature does not make comparisons across sectors, and uses varying metrics for reporting health benefits and effects. This means that additional modeling will be required to definitively compare initiatives across sectors.

Main findings

The main findings relate to each of the major components of the review:

- Transportation
- Buildings
- Urban form
- Food systems
- Waste systems
- Tools and methods for evaluating health impacts

Toronto's inventory shows that about 40% of Toronto's GHG emissions come from the transportation sector and 40% come from natural gas use in buildings. The remaining 20% is approximately half associated with electricity generation from natural gas, most of which is outside the city boundaries, and half is associated with waste management – primarily related to landfill gas emissions at operating or closed landfills outside the city's boundaries.

Within the transportation sector, there are multiple kinds of opportunities related to reducing GHG emissions including: reducing demand, improving fuel efficiency, switching fuels, and changing modes of transport. Of course, many of these opportunities interact. For example, changing modes from vehicular travel to active transportation (cycling or walking) will likely reduce the demand for travel; switching fuels (e.g. electrification) will change efficiency. Regulations governing GHGs and conventional air pollutants from vehicles can be expected to significantly reduce emissions from vehicles as the vehicle stock turns over. However, there is a need to address the total number of vehicles on the road, and to pursue deeper emission reductions over the longer term.

Significant opportunities for reducing health impacts can be expected from increasing active transport, primarily due to the benefits of increased physical activity. Some of these benefits include reduced obesity and type-2 diabetes, reduced cardiovascular disease and some types of cancers, and reduced depression. Safe, appealing infrastructure is needed to encourage and enable active transportation.

The literature points to a number of findings that initially appear to be counterintuitive: the more users adopting active transportation, the lower the risk of injuries and accidents; and most members of car-sharing organizations increase their emissions after joining, but overall car-sharing leads to significant decreases in GHG emissions. These findings highlight diverse opportunities to decrease transportation emissions and improve health, and the need to plan initiatives strategically. An additional transportation opportunity relates to heavy vehicles, and particularly older vehicles, which account for a significant share of overall air pollutant emissions.

Within buildings, there are opportunities to significantly reduce GHG emissions through such things as: decreasing the floor area required, improving the energy efficiency of the building, and switching from fossil fuels to lower-carbon sources of energy. Existing buildings of many types need to be retrofitted to reduce GHG emissions. In making those deep retrofits, care must be taken to manage ventilation and consider the health of occupants. Opportunities to enhance health benefits appear to be particularly significant in older housing where residents have modest incomes. Some of the health benefits reported include: reduced risk of heat-related illness, respiratory infections, stroke, asthma, allergies and respiratory diseases, and improved mental health. Existing and new buildings provide opportunities.

Urban form, though not specifically recognized as a sector within Toronto’s inventory, is where transportation and buildings meet.

Urban form has the potential to encourage higher density development that is more efficient and has lower emissions of both air pollutants and GHGs, to facilitate shifts from vehicular to active transport, to reduce the demand for remaining vehicular travel, and through mixed-use development, to make more services available locally. This includes increasing access to healthy food, which is challenging in some communities. Although some of these initiatives require long time horizons, others can be implemented relatively quickly.

Although the food system is currently outside the scope of Toronto's inventory, typical Canadian diets lead to high levels of GHG emissions, and significant health impacts including obesity-related outcomes. Strategies that can potentially reduce food system GHG emissions and improve health include increasing sustainable production, improving local availability of healthy food, shifting diets to more plant based foods, and reducing food waste. Improving diet also has synergistic benefits when combined with increased physical activity.

Measures have been taken to reduce GHG emissions at Toronto's landfills. Preventing waste benefits health by eliminating potential impacts to air, soil and water form waste transportation, processing and disposal. It also decreases upstream impacts from mining and refining of virgin materials, manufacturing processes, and distribution of materials that are later disposed.

There are a number of tools and methods available to quantify health impacts associated with initiatives that will reduce GHG emissions. The choice of tool will depend on the type of initiative being evaluated, and the end-point of interest.

Conclusions and recommendations

Toronto's GHG inventory is a good starting point for considering opportunities to meet the 2050 GHG-reduction target. Updating the transportation emission estimates is a priority and is being addressed by the City. This will be important for identifying priority areas and tracking progress in meeting GHG-reduction targets. Greater resolution of the inventory would also help in identifying and assessing opportunities, including breaking down transportation emissions by vehicle type and vintage, and building emissions by building type and vintage. For health impact assessment, it would be valuable to have the City inventory resume reporting of conventional air pollutant emissions.

The City may wish to consider explicitly identifying which emissions fall into what are called Scope 1, Scope 2 and Scope 3 initiatives. Some health benefits will be associated with Scope 3 emissions not captured in the inventory, including from upstream food systems and waste systems. It is not clear whether or how inclusion of these would affect GHG-reduction targets or the ability to meet them.

Within the transportation sector, a major focus of the literature is on active transportation where significant net health benefits have been demonstrated in multiple studies from multiple jurisdictions. Benefits are primarily related to health benefits of higher levels of physical activity for the user, and lower vehicle emissions for the broader population. Risks can be minimized through design of safe, appealing, active transportation infrastructure, and the risk of collisions decreases as more people participate in active transportation. Other near-term opportunities include increasing adoption of low/zero-emission technologies, or programs to promote early scrapping of high-emitting, older vehicles.

Within the building sector, as the opportunity for realizing GHG reductions is implemented, it will be important to plan concurrently for health improvements and to monitor actual health impacts to ensure benefits are realized.

Increasing attention to urban form issues; including transportation infrastructure for active transportation, increasing density, and mixed-use development; along with appropriate implementation, can have significant health benefits.

Encouraging changes to the food system, diets, and local availability of healthy food, can result in significant (upstream) GHG reductions, and significant improvements to public health. This is a long-term challenge.

To summarize, priority opportunities to reduce GHG emissions and improve health include:

1. Enabling active transportation, to reduce automobile use and encourage increased physical activity;
2. Retrofitting older, low-income housing, to reduce energy consumption and enable healthy indoor air, temperatures that are safe and comfortable, and improved quality of life;
3. Encouraging faster turnover of older vehicles, and especially of heavy trucks, as those vehicles are the most polluting;
4. Focusing on urban form that promotes increased density, mixed-use development, and non-vehicle transportation; enhancing opportunities for safe active transportation; reducing the demand for energy for transportation and buildings; and making goods and services more readily available;
5. Making changes to the food system to emphasize sustainable, healthy, affordable and locally available foods, to reduce GHG emissions and lower the prevalence of diet-related diseases.

To increase confidence in the conclusions and relative importance of various actions across sectors, the City needs to address the limitations and gaps identified, through both modelling of impacts of initiatives that are proposed, and through assessment and monitoring of those initiatives as they are implemented. Careful implementation is also needed to ensure that health harms are not created.

The City can also continue to show leadership to the community by ensuring that its own facilities and activities promote lower emissions and healthy alternatives, whether through the renewable energy policy for city facilities, retrofitting its own facilities, or greening the City fleet.

Measures identified in the literature for reducing GHGs and promoting public health are largely the ones that the City is already pursuing through such initiatives as Active City, the Toronto Food Strategy, the Toronto Green Standard, Tower Renewal, work on complete streets, and other programs. Continuing and extending these initiatives will enhance health benefits and support reductions in GHGs.

Introduction

This report provides a review from the literature of opportunities to reduce greenhouse gas (GHG) emissions, and the implications of these opportunities for benefiting or harming human health.

The purpose of the report is to assist Toronto Public Health to better understand the health benefits, and any negative health impacts (harms), of GHG-reduction actions that could be taken to achieve the City of Toronto's GHG emission reduction target of 80% by 2050, based on 1990 levels.

The objectives of this report are to, through a review of the literature:

- Identify, quantitatively where possible, the health benefits and harms resulting from potential GHG-reduction actions;
- Identify considerations that could be used to prioritize, through a health lens, GHG-reduction actions for implementation to meet the City's 2050 target; and
- Summarize the approaches and methods for identifying/quantifying net changes in health associated with GHG emission reduction actions.

This report also provides input to TransformTO, a project led by the City of Toronto Environment and Energy Division and the Toronto Atmospheric Fund. The goal of TransformTO is to identify a path that will lead Toronto to a low-carbon future, by reducing GHG emissions by 80% by 2050, while maximizing health, equity and prosperity.

Approach and scope

In undertaking the work we began with a review of general overview literature on the health implications of GHG mitigation actions. From there we drew on more specific actions from the literature that might be applicable to Toronto, and that have not already been implemented. Where possible, we attempted to identify studies that were reviews or meta-analyses of particular issues, and that were relevant to the Toronto context or drew on initiatives in Toronto.

This report is focused on the GHG-reduction actions, and does not attempt to consider health impacts associated with climate change itself, or adaptation measures.

The mitigation actions considered are intended to change technologies, structures or behaviours on an on-going basis. Consequently the health benefits or impacts are also generally effects that are expected to be seen population-wide over a long time period, though they may affect some populations more than others. We report the magnitude of using the actions as identified in the source literature.

We see the project as providing guidance to potential opportunities or issues, as a starting point for more detailed analysis once specific actions to be taken are considered. The report is focused on the actions (e.g. behaviours or technologies) that actually change GHG emissions, rather than the measures (e.g. policies, regulations or financial incentives) that will promote adoption of those behaviours or technologies.

Report overview

The report begins with a broad overview of global studies of GHG mitigation strategies, and the problems (and implicit opportunities) in Toronto, and then considers individual sectors that generate GHGs. It concludes with consideration of the importance of various actions to reduce GHGs when considered through a health lens. Information on methods and models that can be used for more detailed assessment of specific initiatives is appended.

The report is structured as follows:

- GHG mitigation and human health. A brief overview of the research done globally on GHG mitigation and benefits, as well as the current state of GHG emissions and mitigation in Toronto;

- GHG-reduction actions. A description of actions with their associated health benefits and harms, and potential for implementation in Toronto, presented in the following sectors:
    - Transportation
    - Buildings (including energy)
    - Urban form
    - Food systems
    - Waste management;
- Conclusion with recommendations for prioritizing GHG-reduction actions in Toronto from a health perspective;
- Survey of methods for quantifying health benefits and impacts (Appendix A).

Greenhouse gas mitigation and human health

In December 2015, 196 nations met in Paris for the United Nations Framework Convention on Climate Change (UNFCCC) and signed an agreement to take actions on such matters as agriculture, energy and natural resources to slow climate change and to adapt to its impacts. As part of the agreement reached (United Nations Framework Convention on Climate Change, 2015), nations recognized the urgent threat of climate change and agreed to undertake and communicate ambitious efforts. Key among these efforts is the reduction of emissions of greenhouse gases (GHGs) including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and others, most of which are the product of combustion of fossil fuels. GHG mitigation is intimately concerned with the types and quantities of energy that we use.

The Paris Agreement followed a long history of research and commitments related to climate change, including commitments made by Canada, Ontario and the City of Toronto.

While all levels of society reached agreement on the need for action and began setting targets, there was also a growing recognition that reducing GHG emissions would also have implications for human health. For example, a paper published in *Science* in 2001 estimated that actions taken over twenty years in four cities in North and South America would provide major health benefits from associated reductions in particulate matter and ozone ambient concentrations. Improved technologies to reduce fossil-fuel combustion could reduce these co-pollutants by about 10%. This would avoid 64,000 premature deaths (including infant deaths), 65,000 chronic bronchitis cases, and 37 million person-days of restricted activity or work loss in these four cities through 2020 (Cifuentes, Borja-Aburto, Gouveia, Thurston, & Davis, 2001).

In recent years the relationship between climate change mitigation strategies and human health has been the focus of much research.

This includes overviews by the International Panel on Climate Change (IPCC) (K. R. Smith et al., et al., 2014); the World Health Organization and the Lancet Commission (Watts et al., 2015); the US National Institute of Environmental Health Sciences (Interagency Working Group on Climate Change and Health, 2010); and many academic researchers. Some case studies reported by the IPCC working group are summarized in Table 1. The table indicates that, applied on a large geographic scale, GHG mitigation measures have the potential to prevent millions of premature deaths.

Table 1 Example of health benefits from greenhouse gas emissions mitigation

Action	**Where/ when**	**Health precursor**	**Health benefits**
All 400 proposed Black Carbon and CH_4 mitigation measures	Global/ 2030	$PM_{2.5}$	0.7 to 4.6 million avoided premature deaths
			5.3 to 37.4 million avoided years of life lost
		O_3	0.04 to 0.52 million avoided premature deaths
			0.35 to 4.7 million avoided years of life lost
ClimaAPS emission controls	2050	PM & O_3	1.3 million premature deaths
Modify UK housing	UK/ 2009	PM & O_3	850 disability-adjusted life years
CO_2 abatement in electricity generation sector	EU/ China/ India	$PM_{2.5}$	Reduced mortality, especially in India

SOURCE: (K. R. Smith et al., 2014)

When prioritizing GHG mitigation actions that maximize health benefits, the time lag after which health benefits are realized plays an important role in planning. Remais et al. (2014) reviewed various modeling assessments and compiled the time lags associated with health outcomes driven by changes in air quality, diet, and physical activity levels (Table 2).

Table 2 Time lags over which health benefits accrue for the mitigation strategies explored

Health outcome	Likely time lag for health co-benefits
Reductions in sudden cardiac death risk due to reduced air pollution	Days to weeks
Reduction in acute respiratory infections in children due to reduced air pollution	Weeks and months
Reduction in chronic obstructive pulmonary disease (COPD) exacerbations	Weeks and months
Reduction in ischemic heart disease events due to partial substitution of animal source saturated fat consumption by polyunsaturated fats of plant origin	Years
Reduction in type 2 diabetes due to change in physical activity	Years
Reduction in depression due to change in physical activity	Years
Reduction in breast and colon cancer incidence due to change in physical activity	Years
Reduction in COPD prevalence due to reduced air pollution	Decades

SOURCE: (Remais et al., 2014), citing: (Friel et al., 2009a); (Jarrett et al., 2012); (Wilkinson et al., 2009); (Woodcock, Givoni, & Morgan, 2013a).

GHG mitigation in Toronto

Toronto's formal commitment to reduce emissions came in 2007, when Toronto City Council unanimously adopted the City's *Climate Change Action Plan,* which set out targets for reducing emissions of GHGs relative to 1990 levels by 6% by 2012, 30% by 2020 and 80% by 2050. A notable point about the action plan is that it addressed clean air as well as climate change, recognizing the linkage between the two.

Since releasing the plan, the city has achieved the 2012 goal and made progress towards the longer-term goals. The major reductions realized to date were the result of Ontario's phase-out of coal-fired electricity, and from the recovery of methane from landfills. In spite of the improving efficiency of most vehicles, estimated transportation emissions were higher in 2008 than in 1990, and the value for transportation in Toronto's GHG emission inventory has not been updated since that time.

To meet the 80% reduction target, much remains to be done, as shown in Table 3. Actions will be required across multiple sectors or sources of emission, with particular attention to transportation and natural gas (i.e. buildings). As indicated in Table 3, no single sector accounts for the 15 million tonnes that need to be reduced to meet the 80% target, and transportation and natural gas are the two largest sources of GHG emissions in 2013, accounting for approximately 41% and 38% respectively of Toronto's reported emissions.

Table 3 Greenhouse gas emissions (tonnes) in Toronto and reductions realized in 2013 relative to 1990

Source of emission	1990	2013	Reduction to date
Electricity	5,569,300	2,169,947	61%
Natural gas	8,741,625	7,767,622	11%
Transportation	7,293,440	8,383,396	-15%
Waste emissions from City-operated landfills	1,815,751	750,946	59%
Estimated waste emissions from private collection & disposal	3,631,502	1,501,892	59%
Transportation of waste to City-operated landfills		5,066	NA
Estimated transportation of IC&I waste to City-operated landfills		10,132	NA
Total	**27,051,618**	**20,589,001**	**24%**
Further reductions required to realize 80%		15,178,677	

SOURCE: (City of Toronto, 2015)

The values in Table 3 are what are called "scope 2" emissions. Consistent with best practices, the City of Toronto GHG inventory includes emissions released within the city, as well as emissions attributable to electricity used within the city, whether it is generated within or outside the city's borders. The values do not include GHG emissions that are 'embodied' in imported goods and services ("scope 3"). At the household level, those may be almost twice the amount of GHGs released directly (Milito & Gagnon, 2008).

The inclusion of emissions associated with electricity generation is notable, because in many jurisdictions electricity generation is a major source of GHGs, primarily due to the use of coal-fired generation. Ontario phased out its use of coal for electricity generation. While there are still opportunities to make electricity generation in Ontario more sustainable, as shown in Table 4, Ontario has a relatively low use of fossil fuel for electricity generation, and hence relatively low-carbon electricity.

Table 4 Ontario's current electricity mix by fuel type

Fuel type	2015 production (TWh)	%
Nuclear	92.3	60%
Gas	15.4	10%
Hydro	36.3	24%
Wind	9	6%
Biofuel	0.45	0%
Solar	0.25	0%
Total	**153.7**	**100%**

SOURCE: (Independent Electricity System Operator, 2016)

The remaining fossil fuel energy generation is primarily from natural gas. One natural gas electricity generation facility located in Toronto is the Portlands Energy Centre (PEC). PEC has a capacity of 550 MW, and is primarily a peaking facility; the facility runs approximately 40% of the time, typically during peak hours on regular business days (Portlands Energy Centre, 2015). PEC air pollutant emission data, as reported to the National Pollutant Release Inventory, are shown in Table 5 (Environment and Climate Change Canada, 2015).

Table 5 Reportable emissions from the Portlands Energy Centre in 2013 and 2014 (tonnes)

Contaminant	2013	2014
CO	251	356
NO_x (as N_2O)	218	276
PM_{10}	6	6.1
$PM_{2.5}$	6	6.1

SOURCE: (Environment and Climate Change Canada, 2015)

With the exception of electricity emissions, Scope 2 GHG emission analyses do not include GHG emissions released outside the city from processes that serve Toronto residents. (However, the Toronto inventory does include GHG emissions from City-owned waste landfills outside the city's boundaries). For example, they do not include GHG emissions related to:

- Producing, processing, storing and shipping most of Toronto's food, very little of which is produced within the city boundaries
- Upstream processes to produce and deliver the natural gas used for electricity or directly
- Upstream processes to produce and deliver the transportation fuels
- 'Embodied' energy within goods used by Toronto residents (i.e. energy required to extract the materials, process them, manufacture the good, etc. and the GHG emissions associated with this energy use).

This is a standard approach to drawing system boundaries for the purpose of calculating emissions for a particular geographic area. However, there may be opportunities for Toronto residents to reduce provincial, national or global emissions by taking actions that affect these broader sources of emissions that are not captured in Toronto's inventory.

Human health in Toronto

Toronto Public Health has adopted a broad definition of health, consistent with the World Health Organization: "a complete state of physical, mental and social well-being, and not merely the absence of disease or infirmity" (Representatives of 61 States, 1948).

As in other jurisdictions, Toronto-specific assessments of human health point to health-related concerns stemming from energy use in the city, from air pollution to noise. These concerns are often exacerbated when the exposure is to vulnerable persons. For example, patients referred to Toronto Western Hospital for diagnosis or management of a respiratory complaint found a relationship between their risk of ischemic heart disease and their exposure to nitrogen dioxide (NO_2). Nitrogen oxides are generally considered an indicator of transportation-related pollution. Subjects living near major roads and highways had a trend toward an elevated risk of heart disease (Beckerman et al., 2012).

Toronto Public Health looked at the health burden of air pollution, much of which is related to GHG-emitting energy use, and found 670 premature deaths and 1,670 hospital emissions could be attributed to air pollution released in the city (Toronto Public Health, 2014a). A study of traffic–related noise – which has been associated with various health impacts, including cardiovascular disease – in Toronto found that 80% of the monitoring sites were above provincial guidelines (Zuo et al., 2014). An assessment of the spatial analysis of the determinants of pneumonia and influenza hospitalizations in Ontario found they were independently associated with poor housing (Crighton, Elliott, Moineddin, Kanaroglou, & Upshur, 2007), which typically also has very poor energy performance. Many of these associations provide examples of how implementing a change to reduce GHG emissions could also have potential benefits for health.

A broad set of actions to reduce GHGs that are considered in this document, and their potential benefit to health, are summarized in Table 6.

Table 6 Measures to mitigate greenhouse gas emissions and to improve human health

	Fewer GHG emissions	Less air pollution	Reduce accidents	Better indoor air	Less noise	More physical activity
Reduce transportation demand	✔	✔	✔		✔	
Improve fuel efficiency	✔	✔				
Switch to lower-carbon fuels	✔	✔			✔	
Switch to lower-carbon modes	✔	✔	✔		✔	✔
Use more compact or denser buildings	✔	✔				
Make buildings more energy efficient	✔	✔		✔	✔	
Switch to lower-carbon fuels	✔	✔				
Design the city to promote active transportation	✔	✔	✔			✔
Reduce waste going to landfill	✔	✔				
Recover landfill gases	✔	✔				
Promote healthier diets	✔					✔

Realizing these health benefits will necessitate undertaking the measures carefully, with appropriate consideration to their impact on health. Considering potential GHG-reduction actions from a health perspective enables any health harms to be avoided or mitigated, and health benefits to be maximized.

Transportation

Transportation (including waste transport) was estimated to account for more than 40% of Toronto's GHG emissions in the City's GHG inventory (Table 7), and it has shown an increasing trend since 1990 (City of Toronto, 2015). Transportation accounted for over 80% of nitrogen oxides (NO_x) emissions in the city, as shown in Table 7. This suggests that reducing transportation emissions will be essential for reaching the City's 2050 target, and should be a priority from a health perspective.

The City acknowledges that there are limitations with its assessment of emissions from the transportation sector. The City is working on updating these values, as the estimates being used currently are from 2008.

Table 7 Greenhouse gas emissions and air quality in Toronto

Emissions source	Greenhouse gases (tonnes)	Ref.	Greenhouse gases (%)	Air quality (as NO_X) (tonnes)	Ref.	Air quality (as NO_X) (%)
Cars & Light Trucks	6,281,550	D	31%	11,446	C	37%
Heavy Gas Trucks plus Other Vehicles	510,536	C,D	2%	2,299	C	7%
Heavy Diesel Trucks	1,591,311	C,D	8%	12,251	C	40%
Transportation of waste to landfills	15,198	A	0%	Not available	---	---
Transportation sub-total	8,398,595		41%	25,996		84%
Natural gas	7,767,622	A	38%	4,752	B	15%
Electricity	2,169,947	A	11%	250	B	0%
Waste	2,252,838	A	11%	Not available	---	---
Totals	20,589,002	A	100%	30,998		100%

Notes: In the table, "Ref." denotes the reference from which the values in tonnes were obtained. The table is compiled from City of Toronto GHG inventory reports for 2011, 2012 and 2013, using the most recent reference available for each value. Please see original reports for detailed notes on emission estimates.

References are as follows: Reference A (City of Toronto, 2015); Reference B (City of Toronto, 2014a); Reference C (City of Toronto, 2013); Reference D (Fernandez, 2016).

A separate assessment of transportation emissions, in this case for the entire Toronto Metropolitan Area, was undertaken by McMaster University's Institute for Transportation and Logistics, and the results are summarized in Table 8. Similar to the Toronto inventory, this analysis indicates that transportation is a significant source of GHGs and criteria contaminants, including NO_x.

Table 8 Vehicle emissions in the Toronto Census Metropolitan Area in 2011 (tonnes).

Vehicle Type	CO_2	CH_4	CO_2e	NO_x	CO	HC	NH_3	PM2.5 total	PM10 total	VOCs
Light Duty Passenger Vehicles (PVs)	8,532,087	724	8,550,187	13,694	155,921	14,906	739	467	505	13,950
Light Duty Commercial Vehicles (CVLs)	1,391,380	110	1,394,141	2,639	22,175	1,621	85	69	74	1,487
Medium Duty Commercial Vehicles (CVMs)	894,422	26	895,079	4,494	5,543	618	26	204	210	603
Heavy Duty Commercial Vehicles (CVHs)	1,131,827	103	1,134,410	7,089	2,255	628	14	289	298	541
City Buses	66,534	1	66,563	475	501	46	1	25	26	31
Total	**12,016,250**	**965**	**12,040,380**	**28,391**	**186,394**	**17,818**	**864**	**1,054**	**1,113**	**16,612**

SOURCE: (McMaster Institute for Transportation and Logistics, 2014)

There are several assessments of health impacts associated with transportation in Toronto. A 2007 analysis estimated the number of premature deaths and the costs that could be avoided with a reduction in traffic emissions (Toronto Public Health, 2007). Key findings are shown in Table 9. Reducing emissions by 20%, the mid-range scenario, it is estimated that 126 deaths could be avoided, and a $600 million benefit could be realized.

Table 9 Estimated annual number of premature deaths avoided and its economic benefit, as a result of traffic reduction in Toronto

Emission Scenario (% reduction in pollutant emissions)	Deaths Avoided (number)	Value of Health Benefits (Million $)
10	63	300
20	126	600
30	189	900

SOURCE: (Toronto Public Health, 2007)

Based on the 2006 census, 7.1% of Torontonians walk to work, and 1.7% cycle to work (Statistics Canada, 2006). According to the 2011 Transportation Tomorrow Survey (TTS), walking and cycling make up 9% of trips for all purposes. The overall TTS mode shares for all trips made by City of Toronto residents are illustrated in Table 10. Mode share describes the percentage of travelers using a particular type (mode) of transportation.

Table 10 Mode shares for all trips made by Toronto residents

Mode of Travel	2006	2011	Change between 2006 and 2011
Auto driver	52%	50%	-2%
Auto passenger	15%	14%	-1%
Public transit	23%	24%	1%
Walk and cycle	8%	9%	1%
Other	2%	2%	0%

SOURCE: (Data Management Group, 2011)

On-road motor vehicles are one of the largest contributors to air pollution in urban environments (Franco et al., 2013). Primary means of reducing GHGs from transportation, and their health benefits and impacts, come from reducing demand, increasing fuel efficiency, fuel switching, and mode switching. This section identifies GHG-mitigation options with potential health benefits in the following categories:

- Transportation demand reduction (e.g. fewer vehicle kilometres);
- Increasing vehicle fuel efficiency (e.g. lower L/100 km);
- Fuel switching for vehicles (e.g. from gasoline to electric); and
- Mode shifting (e.g. from automobile to cycling).

The primary health drivers with regard to GHG mitigation actions are through changes in air pollution, changes in level of physical activity, changes in traffic-related injuries, and changes in traffic-related noise. The health benefits from reduced vehicle emissions are discussed together, later in this report.

Transportation demand reduction

The most effective way of reducing both GHG emissions and health impacts associated with transportation is to reduce the demand for transportation in the first place, as measured by vehicle-kilometres traveled. There are several strategies for realizing this, which vary depending on whether passenger or freight transportation is being considered.

Passenger transportation

There are multiple strategies that may reduce the need for transportation, while preserving or enhancing mobility. These include:

- Carpooling/ car sharing/ ride sharing
- Substituting telecommunications and teleworking
- Trip consolidation
- Denser urban design / distribution of services

The first two strategies are described here. Trip consolidation involves planning trips efficiently, and can be applied to any mode of transportation. Denser urban design is discussed in the Urban Form section of this report.

Carpooling, car sharing and ride sharing

Carpooling, car sharing and ride sharing are all means of reducing the demand for transportation while maintaining mobility. Most trips by Toronto residents are made by automobile. The Transportation Tomorrow Survey suggests about 64% of all trips in the city are by automobile, and most of those (more than 70%) are trips by the driver travelling alone (Data Management Group, 2011).

Determining what motivates people to participate in carpooling is complicated. A recent meta-analysis of 22 studies of carpooling identified 24 factors in four categories: demographic (e.g. age, income, car ownership); judgemental (save money, reduce congestion, reliability); interventions (e.g. mechanisms such as HOV lanes, cost subsidies, or emergency rides home such as offered by Metrolinx's SmartCommute program); and situational factors (e.g. regular work hours, commute distance and time, number of employees) (Neoh, Chipulu, & Marshall, 2015).

Nevertheless, the potential for carpooling and the more general ride-sharing, which includes services like Uber, appears to be very substantial. A study of four cities found that traffic in Madrid could be reduced by 59% if users are willing to share a ride with people who live and work within one kilometre. Results for other cities depended on density, with the potential 14% higher in Barcelona than Madrid, and 46% lower in Los Angeles than New York City (Cici, Markopoulou, Frías-Martínez, & Laoutaris, 2013). Cici et al. recognized that this is an upper bound estimate, and show lower values depending on people's willingness to wait less than 10 minutes, or to only ride with friends or friends of friends. Even in 2006, ride-sharing represented about 8% of the transportation modal share in Canada (Chan & Shaheen, 2012), and was presumably even higher in Toronto.

An analysis of transportation in the San Francisco Bay Area found a significant potential for reducing vehicle demand by ride sharing, and found that a moderate ridesharing scenario compared favourably with transit oriented development (Rodier, Alemi, & Smith, 2016), realizing a 9% reduction in vehicle-kilometres. With a 10 to 30% increase in the costs of automobiles, vehicle-kilometre reductions were estimated to be 11% to 19%.

Car sharing also appears to have the potential to reduce automobile use, and associated emissions of GHGs, air pollution, and noise. A study of North American car sharing programs, that included Toronto's AutoShare and ZipCar, found that the majority of car sharing members are from carless households, and they increase their emissions after taking out car sharing memberships. However, these emission increases are more than offset by a small number of participants who dramatically decrease the GHG emissions for which they are responsible (Martin & Shaheen, 2010). Overall, participating in a car sharing program was estimated to result in a net reduction of GHGs per household of 0.58 tonnes per annum (0.84 t/a if auto use that would have occurred in the absence of car sharing is taken into account). Martin & Shaheen (2010) tested the sensitivity of the conclusions to a variety of assumptions and data modifications and found that the conclusions were robust.

A study of car sharing in Vancouver found multiple benefits, beyond reduction in the demand for vehicle-kilometres (which it attributed to trip planning). Benefits included mode shifting (higher use of other modes of mobility such as walking, cycling and public transit), right sizing (selecting the appropriate vehicle for the task at hand), the use of newer (and hence more fuel-efficient) vehicles, and more efficient vehicles, for each vehicle type (Namazu & Dowlatabadi, 2015). Estimated emission reductions varied with different household types. Households without children showing the greatest reductions in GHGs (55%), of which 19-20% comes from the newer, more fuel-efficient fleet, 16-19% from vehicle optimization, 2-8% from trip aggregation, and additional savings for a total of 42-54% from mode shifting (Namazu & Dowlatabadi, 2015). The Namazu study did not consider reductions in emissions of criteria air contaminants (CACs)[1] or noise, and suggests that those ought to be studied.

A systematic review of the literature (J. L. Kent, 2014) that looked at car sharing through a health lens identified three key benefits:

- Reduced car ownership, which is connected with acute morbidity and mortality from car collisions, increases in

[1] Criteria air contaminants are 'conventional' air pollutants, including nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs), ozone (O_3), and sulphur dioxide (SO_2).

physical inactivity, stress and other impacts of congestion and 'busyness', and loss of community cohesion;

- Reduced vehicle-kilometres traveled (though the author finds the evidence less conclusive than evidence of reduced car ownership, and that reduced distance travelled may be more a result of reduced car ownership); and
- Increased uptake of active transportation. Four of seven papers analyzed reported increases in walking, cycling and public transport use related to a car sharing membership.

Telecommunications and teleworking

Some transportation may be substituted by telecommunications, reducing the impacts associated with transportation. One form of regular substitution is telecommuting. Overall, a review of many aspects of telecommuting concluded that there is not a definitive answer on whether or not telecommuting is beneficial to health or to GHG emissions reductions (Allen, Golden, & Shockley, 2015).

Some studies found that telecommuting resulted in noticeable reductions in vehicle-kilometres travelled and GHG and some but not all other emissions (Kitou & Horvath, 2003). Others found that vehicle-kilometres were actually greater for those who telecommute (Zhu & Mason, 2014), and that access to telecommuting permitted people to live farther from their workplace. Some analysts found that telecommuters had higher levels of walking and cycling (Mokhtarian & Varma, 1998). Others identified health risks associated with commuting by automobile: commuting distance is adversely associated with moderate-to-vigorous physical activity, cardiorespiratory fitness, adiposity, and blood pressure (Hoehner, Barlow, Allen, & Schootman, 2012). Other health considerations related to telecommuting include the (lack of) access to ergonomic equipment at home, and the possibility that workers eat healthier food at home than at the workplace (Allen et al., 2015).

Freight transportation

The quantity of goods requiring shipping may be reduced through various dematerialization processes, which will also result in less waste (see Waste Management section of this report). Demand for shipping may also be reduced through changes in urban form (see Urban Form section of this report). Operational and other options can reduce the fuel use or emissions from moving freight in the city. A recent review of research on green road transport (Demir, Bektaş, & Laporte, 2014) identifies a number of potential strategies, that are summarized in Table 11, based on various measures to reduce fuel use or emissions.

Table 11 Operational measures to reduce fuel, greenhouse gases or emissions from freight transportation

Measure	Potential results	Source
Eco-routing considering traffic information, geographic information and vehicle parameters	9% reduction in fuel, 9% increase in travel time	Kono, Fushiki, Asada, & Nakano 2008
Eco-routing in France	1-36% fuel savings	Correia, Amaya, Meyer, Kumagai, & Okude 2010
Design service areas and routes to minimize CO_2 emissions	20 -23% reductions in CO_2	Ramos, Gomes, & Barbosa-Póvoa 2012
Optimize waiting to avoid congestion	20% reduction in fuel, CO_2 emissions and driver cost	Franceschetti, Honhon, Van Woensel, Bektas, & Laporte 2013
Optimize departure times to avoid congestion	20% reduction in emissions and fuel consumption	Solomon 1987
Pooling supply chain networks	14% reduction in CO_2 emissions achieved	Pan, Ballot, Fontane 2010
Minimize total travel time by predicting congestion and road work	7% CO_2 savings	Maden, Eglese & Black 2010
Strategic planning of one-to-many distribution systems	50% reduction in emissions	Saberi and Verbas 2012
Optimize routing networks for waste transportation	52% fuel savings compared with distance minimization	Tavares, Zsigraiova, Semiao & Carvalho 2008
Optimize municipal solid waste collection to minimize fuel consumption	Reduce distance by 29% and fuel consumption by 16%	Tavares, Zsigraiova, Semiao & Carvalho 2009
Optimize municipal waste collection (in Serbia)	20% reduction in costs and emissions	Jovičic et al. (2010)
Eco-routing	CO_2 savings of up to 18%	Kang, Ma, Ma, and Huang (2011)
Use a heterogenous fleet to minimize emissions	"Significant" reductions	Kopfer, Schönberger, and Kopfer (in press)

ADAPTED FROM (Demir et al., 2014)

Increasing vehicle fuel efficiency

Vehicle fuel efficiency will increase in coming years as a result of federal regulations to reduce GHG emissions from new vehicles. These will have increasing effects as the stock of vehicles turns over. The fleet average reduction (for new vehicles) is approximately 5% per year for automobiles, and 3.5% per year for light trucks, compared to 2016 models, between 2017 and 2025 (Government of Canada, 2012). The results are likely to be achieved through a mix of engine improvements, aerodynamics, and light-weighting.

However, in general, emissions of criteria air contaminants from vehicles are regulated by distance (i.e. g/km), and vehicles are designed to meet these regulations. Consequently, reductions in criteria air contaminants cannot be expected to decrease at the same rate as GHG emissions as a result of these regulations. There are separate regulations that will reduce the emissions of criteria air contaminants in Canadian vehicles, and these regulations are consistent with regulations in the United States (Canada Minister of Justice, 2015). Reductions from regulations can be significant. For example, Figure 1 shows how emission factors for new vehicles have fallen relative to 1990 for passenger automobiles (Cai, Burnham, & Wang, 2013).

Vehicle emissions in southern Ontario are also regulated by the provincial government through "Drive Clean", an emissions testing program that targets in-use, light-duty vehicles whose emissions exceed US EPA Tier 1 limits (McCarter, 2012; MoE, 2010). The objective of the Drive Clean program is to remove high-emitting vehicles (Wang et al., 2015).

Wang et al. (2015) conducted a study analyzing vehicle plumes in Toronto and found that the 6% of vehicles with high NO_x and CO emission factors that exceeded the Drive Clean limit also contribute 26% of NO_x and 54% of CO. This disproportionate contribution of emissions from a small number of vehicles demonstrates the importance of targeting the highest-emitting vehicles, and infiltration of cleaner vehicles into the consumer market (Wang et al., 2015). However, there is room for further removal of higher emitters. Drive Clean only tests vehicles at cruise speeds which may not reflect real-world driving conditions, and enable some higher-emitting vehicles that are not high-emitters at cruise speeds to pass emissions testing (Wang et al., 2015).

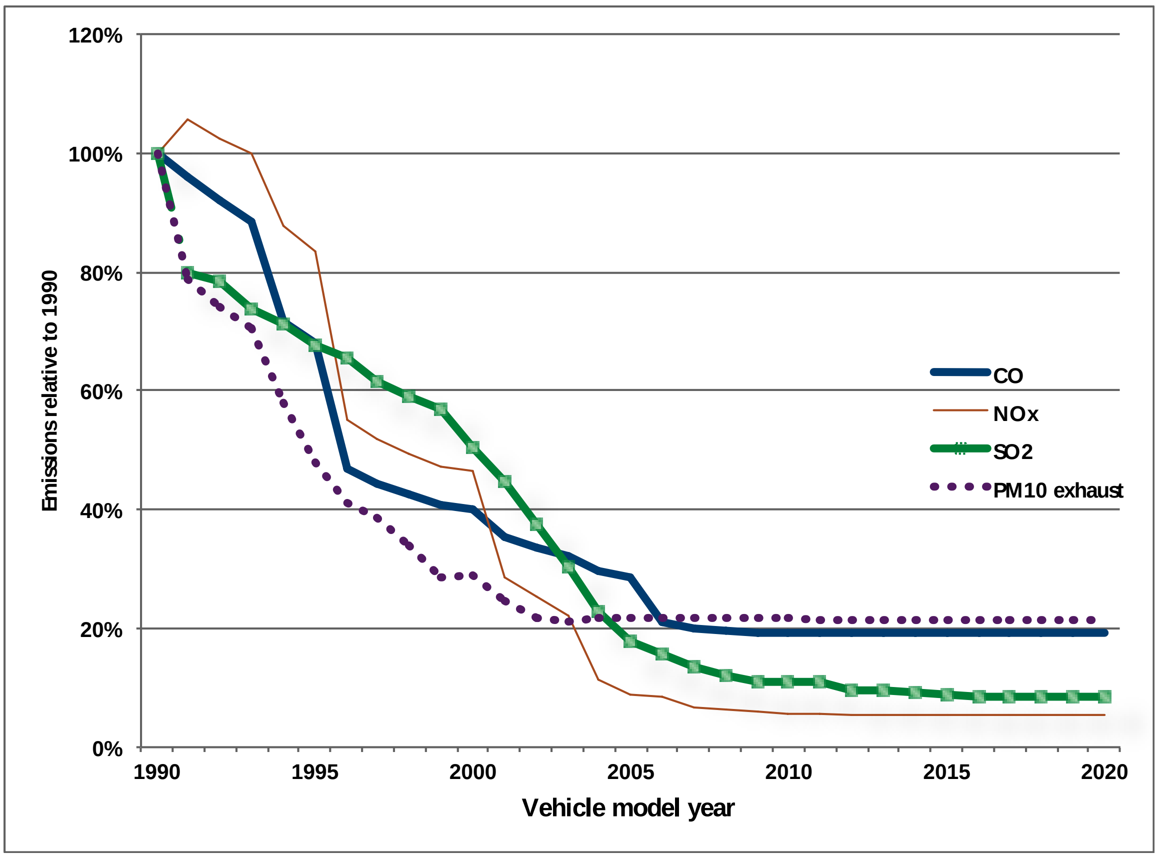

Figure 1 Lifetime distance-weighted average air pollutant emission factors for gasoline passenger cars for model years 1990-2020, relative to 1990, based on data from (Cai, Burnham, & Wang, 2013).

Canada, in harmony with the United States, has been introducing regulations that reduce the allowable emissions of both CO_2 and other pollutants from heavier vehicles as well. In some cases, these reductions are dramatic. For example, lifetime distance-weighted average NO_x emission factors (g/km) for diesel combination shorthaul trucks are expected to drop from what was 20.14 g/km for 1990 model vehicles, to 3.17 in 2007, and to 0.88 g/km in 2020 (Cai, Burnham, & Wang, 2013).

In Toronto, heavy diesel trucks are estimated to contribute approximately 8% of GHGs and 40% of NO_X (see Table 7). As summarized by Toronto Public Health from federal data, in 2009, heavy vehicles made up only 1.5% of vehicles in Canada, but in contrast heavy vehicles including trucks generated almost 80% of $PM_{2.5}$ and over half of NO_X emissions in Ontario at that time (Toronto Public Health, 2014a).

As with automobiles, we can expect a disproportionate share of emissions to come from older trucks. About 48% of all trucks on Ontario's roads are 9 years old or older (Transport Canada, 2016). To accelerate reductions in both GHG emissions and other air pollutants, it would be necessary to encourage rapid turnover of the stock. Other jurisdictions have approached this in different ways. The Port of New York/New Jersey offers financial incentives for owners of older trucks to replace their vehicles, paying up to half the cost (Gillis, 2015). California also has incentives to reduce emissions related to highway transport (California Environmental Protection Agency, 2015).

Other jurisdictions have limited access of older, more polluting vehicles within the city in Low Emission Zones (LEZs). For example in 2015, Paris announced plans to restrict access of vehicles from before 1997 from the City (City of Paris, 2015). LEZs have been implemented in London since 2008, though the impact on particulates and nitrogen oxides has been very limited (Ellison, Greaves, & Hensher, 2013).

Concerns have been raised about decreased safety resulting from light-weighting. An analysis of the relationship between vehicle size/weight and safety found that there is a relatively weak relationship between carbon footprint and casualty risk to drivers of individual vehicle models (for both cars and light trucks). Conversely, the study found that vehicle design and safety, such as the inclusion of side door airbags, will have a greater effect on health than will fuel economy standards (Wenzel, 2013).

Progress has been made in improving fuel efficiency and reducing emissions of GHGs and air pollutants through regulation. Progress will continue as these requirements become more stringent in the coming years and the vehicle fleet turns over. Nonetheless, there is a need to address the total number of vehicles on the road, and to pursue deeper emission reductions over the longer term.

Fuel switching

Different fuels have different emissions of both GHGs and criteria air contaminants. For example, Table 12 shows this variation for transit buses using a range of conventional and alternative fuels (Ercan, Zhao, Tatari, & Pazour, 2015).

Table 12 Lifetime tailpipe emissions for various urban buses by fuel

Vehicle Lifetime Emissions [tonnes]	Diesel	Hybrid	20% Biodiesel	CNG	LNG	Battery Electric
CO_2	877	696	890	728	731	–
CO	0.36	0.22	0.33	6.43	6.43	–
NO_x	0.48	0.34	0.49	1.32	1.32	–
PM10	0.03	0.03	0.03	0.02	0.02	–
PM2.5	0.01	0.01	0.01	0.01	0.01	–

Notes: Emissions of CO2 varied with the driving cycle (see source)

SOURCE: (Ercan et al., 2015)

Governments around the world, including the federal and provincial governments, have made commitments to promoting electric vehicles, including personal vehicles, through tax incentives and support for the development of infrastructure, such as charging stations. Some analysts have suggested we will not achieve deep GHG emission reductions without significant electrification of transportation (Williams et al., 2012).

Electric vehicles

Electric vehicles have the potential to reduce emissions from the transportation sector, and are generally quieter than conventional vehicles. Electric vehicle technology is rapidly changing, but still represents a tiny portion of the overall vehicle market. As of the end of 2015, the Ontario fleet consisted of 3,428 battery electric vehicles, and 2,507 plug-in hybrid electric vehicles (Stevens, 2016). In contrast, the entire Ontario fleet consisted of 4,071,000 vehicles (Transport Canada, 2016). A 2013 assessment of the potential market size anticipated significant growth in personal electric vehicles after 2030 in a scenario driven by climate policy, with both battery electric vehicles and plug-in hybrid electric vehicles each providing more passenger-kilometres by 2050 than fossil-fuel powered vehicles (Bahn, Marcy, Vaillancourt, & Waaub, 2013).

For battery electric vehicles, there are no tail-pipe emissions, though there will be upstream emissions related to vehicle and battery manufacturing, and electricity generation (if electricity isn't carbon-free at the time of vehicle charging). Where electricity is coal-fired, some emissions are worse as a result of electric vehicles, but there are benefits in jurisdictions that have phased out coal, including Ontario, where electricity is not very carbon intensive (Hawkins, Gausen, & Strømman, 2012). Co-implementation of battery recycling facilities with the growth in the use of batteries in electric cars will be important to minimize local impacts of metals used in batteries (Dunn, Gaines, Kelly, James, & Gallagher, 2014). When considering the GHG and health implications of electric vehicles, the lifecycle impacts of the vehicles and energy they consume must be compared against the lifecycle impacts of the conventional vehicles and fossil fuels that power them.

Electricity may also be used to power heavy vehicles, including urban buses and others. There is a growing market for the use of electric urban buses, and some analysts see a bigger opportunity for electric vehicles in urban transit than in personal vehicles (Linse & Barasz, 2015). An additional benefit beyond reduction in GHG emissions and conventional pollutants is that electric buses are quieter than their diesel counterparts (Wang & González, 2013).

Quieter electric vehicles may make road users more vulnerable to injury risks since pedestrians and cyclists rely on both visual and auditory signals to avoid collisions. People with visual impairments are especially at risk. Warning sounds on electric vehicles have been introduced to alert pedestrians they are approaching and to avoid traffic collisions. Although Canadian noise abatement policy is primarily driven by "annoyance" and by noise impact on property value (Curran, Ward, Shum, & Davies, 2013), Wogalter, Lim, & Nyeste (2014) found that 70% of surveyed U.S. residents relied on vehicle sounds when crossing the street, and that 73% agreed that sound added to an otherwise quiet vehicle would be useful to pedestrians and drivers in making them aware of vehicle movement and speed. Not all sounds were acceptable: participants largely recommended engine and hum noises as being preferable.

Compressed natural gas

Compressed natural gas (CNG) has the potential to achieve GHG emissions savings comparable to diesel, with lower PM emissions. The shift from diesel to CNG in truck fleets has the potential for health benefits from reduced air pollution (Hosking, Mudu, & Dora, 2011).

Numerous studies have been done of the emissions implications of CNG-powered, heavy trucks for refuse collection, with somewhat differing results. An evaluation of a switch to CNG refuse trucks from diesel trucks in Surrey BC found GHG reductions of 24% CO_2-equivalent and 44% in NO_x (Rose et al., 2013). Rose et al. (2013) reviewed other studies on life-cycle impacts of CNG in transit buses and refuse trucks and discuss how local situations impact findings. Although they see the potential for electric refuse collection vehicles in the longer term, CNG is seen as an immediate opportunity that reduces GHG emissions and is cost-effective. In contrast, other studies found no reductions in GHG emissions from CNG refuse-collection trucks (Fontaras et al., 2012; Tong, Jaramillo, & Azevedo, 2015). The California Air Resources Board database indicates that CNG has a carbon intensity that ranges from slightly higher to much lower than that of gasoline or diesel fuel (as g eCO_2/MJ) (California Air Resources Board, n.d.). Fontaras et al. (2012) observed noticeable reductions in NO_x and particulates.

Biofuels

There is an extensive body of research on biofuels, and findings are generally highly specific to the source and type of biomass. For instance, research has found that while cellulosic ethanol could potentially reduce $PM_{2.5}$ and GHG emissions relative to gasoline, corn ethanol may increase $PM_{2.5}$ emissions without reducing GHG emissions (Hosking et al., 2011). The California Air Resources Board maintains an extensive database of the carbon intensity of biofuels manufactured through various pathways, relative to conventional transportation fuels (California Air Resources Board, n.d.).

Diesel

There has been a shift from gasoline to diesel fuels. However, this shift may actually worsen human exposures to small airborne particulate matter (PM_{10} and $PM_{2.5}$), which has been linked to respiratory and cardiovascular morbidity and mortality (e.g. asthma and lung cancer) (WHO, 2013). Modeling efforts have also shown that converting the gasoline-powered fleet in the United States to modern diesel vehicles may increase photochemical smog (Hosking et al., 2011). The risk of this is further confounded by recent accusations of falsified testing results on popular diesel cars (EPA, 2016). Extensive research has been done on the GHG emissions and health implications of diesel fuel, and the findings warrant further examination.

Mode switching

Within Toronto, the primary opportunities for mode shifting relate to passenger transportation, and in particular shifting from private automobiles to public transit or active transportation. As illustrated in Table 13, the mode chosen affects the emissions of both GHGs and air pollutants. (Older model vehicles will have higher emission values).

Table 13 Air pollution and greenhouse gases from different commuting modes for 2015 model year vehicles, weighted over their lifetimes (g/person-km)

Vehicle type	VOC	CO	NOx	SO2	PM10	PM2.5
Walking	-	-	-	-	-	-
Cycling	-	-	-	-	-	-
Gasoline automobile (1 occupant)	0.1054	1.780352	0.074689	0.002734	0.0206	0.0116
2-person caroll in gasoline automobile	0.0527	0.8902	0.0373	0.0014	0.0103	0.0058
Gasoline passenger truck (1 occupant)	0.1712	3.074233	0.192563	0.003542	0.0324	0.0192
Diesel passenger truck (1 occupant)	0.0483	0.824124	0.588563	0.002858	0.0289	0.0164
Diesel transit bus with 10 passengers	0.0054	0.0673	0.0751	0.0006	0.0055	0.0032
Diesel transit bus with 40 passengers	0.0013	0.0168	0.0188	0.0001	0.0014	0.0008

SOURCE: Based on emission factors in (Cai, Burnham, & Wang, 2013)

Achieving a mode shift from vehicles to more active forms of transportation such as walking and cycling is feasible. About 55% of all trips in Toronto are less than 7 km, and are therefore very conducive to cycling. Over 20% of all trips are under 2 km and very walkable (Toronto Public Health, 2014a).

The modal split for both Toronto residents and travellers to Toronto stayed relatively consistent between 1985 and 2011 (Data Management Group, 2011). In terms of total number of trips, the number of trips taken by travellers to the City is growing faster than trips taken by Toronto residents, as illustrated in Figure 2 for the morning rush hour. Figure 2 shows trips by all modes of transportation: driver, passenger, transit, GO transit, walking, cycling and other.

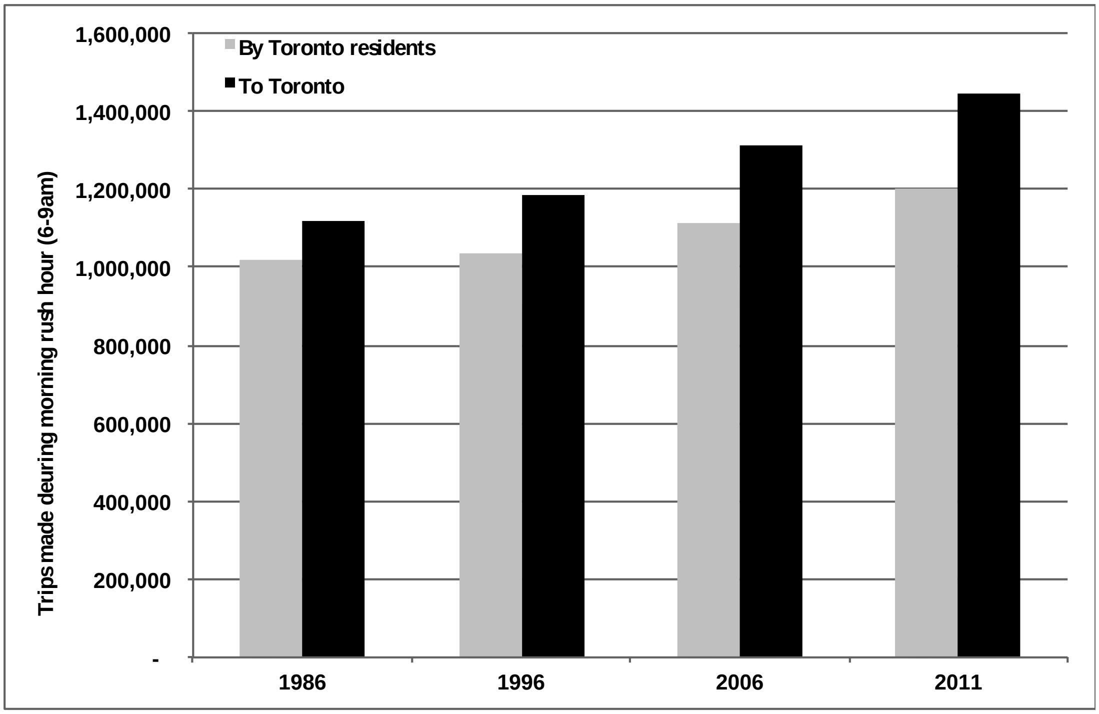

Figure 2 Trips taken during Toronto's morning rush hour (6:00-9:00 am) by Toronto residents and travelers to Toronto (Data Management Group, 2011)

Active transportation

Active transport is another attractive, environmentally friendly transportation alternative, particularly for shorter journeys. Active transportation, including travelling on foot, by bicycle, and by other non-motorized transport, is recognized as a largely "zero-emission" means of travel. Torontonians are already increasingly taking part in active transportation; walking and cycling have been increasing modestly in Toronto since 1986 (Data Management Group, 2011). Evidence from the literature is presented below on the significant health benefits of active transportation experienced by individuals and the population, when increasing physical activity. Benefits from motor vehicle traffic reduction are also discussed.

Active transportation as a source of physical activity

Physical activity is a crucial part of staying healthy, and active transportation provides an opportunity to incorporate frequent physical activity into daily living, which could help people achieve recommended levels of physical activity. The Canadian Physical Activity Guidelines recommend that all adults aged 18 and over obtain 150 minutes of physical activity each week, in sessions of at least 10 minutes. This corresponds to 30 minutes of physical activity (a 2 km walking trip or a 7.5 km biking trip), 5 days per week (Toronto Public Health, 2012a).

Oja et al. (2011) conducted a systematic review of the health benefits of cycling and reported a strong positive relationship for cardiorespiratory fitness in adults and moderate evidence for cardiovascular benefits in adults. There was inconclusive evidence for an inverse relationship between commuter cycling and all-cause mortality, mortality and morbidity by coronary heart disease, cancer risk, and obesity. Another systematic review reported a reduction in all-cause mortality risk of 19% in populations who have 30 minutes daily of moderate intensity activity 5 days per week, compared with those with no activity (Woodcock, Franco, Orsini, & Roberts, 2011). When populations engaged in 7 hours of moderate activity weekly, the all-cause mortality risk dropped by 24% compared to those with no activity. A Scandinavian study reported that all-cause mortality rates in moderately and highly active persons were 50% lower than those with no activity. In addition, the study found that cycling to work would also reduce all-cause mortality rates by 40% (Andersen, Schnohr, Schroll, & Hein, 2000).

Active transportation may be a particularly important source of exercise for Torontonians. Although guidelines for physical activity like the Canadian Physical Activity Guidelines have been provided for a long time, inactive lifestyles still remain a public health problem. Reliance on private motorized transport can be a significant contributing factor to sedentary lifestyles associated with obesity and diabetes. Increased active transport could reduce GHG emissions and disease burden from ischemic heart disease, cerebrovascular disease, depression, Alzheimer's disease, diabetes, and breast and colon cancer (Hosking et al., 2011). To date, physical inactivity has been regarded as one of the most risky behavioural factors contributing to disease burden, especially in large, developed metropolitan cities like Toronto (Xia, Zhang, Crabb, & Shah, 2013). Almost half (48.9%) of Torontonians reported being inactive during leisure time between 2013 and 2014 (Public Health Ontario, 2016).

Increased fitness and reduced obesity

Active transport has also been shown to strengthen fitness. A British study found that the children who walked or cycled to school were fitter than those who traveled to school by car or bus, with 30% higher vigour in boys who took active transport and seven times higher in girls (Voss & Sandercock, 2010).

Active travelling may be regarded as an efficient approach to combat obesity. Xu, Wen, & Rissel (2013) reported that taking active transport to work or school has been associated with lower body weight. Moreover, an Australian study suggested that men who drove to work were more likely to be obese or overweight than those who cycled (Wen & Rissel, 2008). Research investigating the obesity levels in Europe, North America, and Australia reported an inverse relationship between active transport levels and obesity levels in the population, and suggests that active transport might be an important contributing factor to international differences in obesity rates (Bassett, Pucher, Buehler, Thompson, & Crouter, 2008).

Reduced burden of illness

Moderate intensity physical activities, including walking and cycling, have also been demonstrated to decrease the morbidity of many chronic diseases such as diabetes, cardiovascular disease, breast cancer, colon cancer, and dementia (Woodcock et al., 2009). Jeon, Lokken, Hu, & van Dam (2007) reviewed ten prospective cohort studies and found that the risk of type 2 diabetes was 31% lower for participants who engaged in regular moderate intensity physical activity, and found 30% less risk for a regular walking population, compared with almost no walking. Xu, Wen, & Rissel (2013) found a significant positive association between active transport to work or school and cardiovascular health. Physical activity was also found to reduce the risk of postmenopausal breast cancer by 20–80%, with a further 6% reduction with each additional hour of physical activity per week (Monninkhof et al., TFPAC, 2007).

A summary of the impacts of physical activity on health risks is presented in Table 14, expressed as relative risk. Relative risk is the risk of the outcome after the exposure, compared to without the exposure. For example, a relative risk of 1 means that there is no difference in risk for the health outcome before and after the exposure; a relative risk greater than 1 means there is a higher risk of the outcome after exposure; and a relative risk less than 1 means a lower risk. The table indicates that physical exercise lowers the risk of most of the health effects shown.

Table 14 Relative risk of health endpoints after exposure to physical exercise

Outcome	Review/study	Exposure	Relative risk (95% CI)
Coronary Heart Disease	(Zheng et al. 2009)	Increment of 8 MET-h/week walking*	0.81 (0.77-0.86)
Cardiovascular disease	(Hamer and Chida 2008)	Walking (3hours or 9.8 km per week or 7.5 METs/week)	0.84 (0.79-0.90)
Dementia	(Hamer and Chida 2008)	33 METs or > 1657kcal/week	0.72 (0.60-0.86)
Diabetes	(Jeon et al. 2007)	10 METs/week	0·83 (0·75-0·91)
Breast cancer	(Monninkhof et al. 2007)	Each additional h per week	0·94 (0·92-0·97)
Colon cancer	(Harriss et al. 2009)	METs per week: 30·1 for men and 30·9 for women	Men 0·80 (0·67-0·96); women 0·86 (0·76 to 0·98)
Depression	(Paffenbarger Jr et al. 1994)	6·9 METs per week (<1000 kcal per week);	1
		24·2 METs per week (1000-2499 kcal per week);	0.83
		63·7 METs per week (≥2500 kcal per week)	0.72

SOURCE: (de Nazelle et al., 2011)

Reduced air pollution

The health implications of reduced air pollution from traffic generally, are discussed later in this report. Air pollution considerations related to active transportation are introduced here.

Studies that describe the exposure to air pollution for different commuting modes show different results. A study comparing air pollution exposures across different modes of transportation in Sydney, Australia found that car commuters recorded the highest exposure to pollutant levels for VOCs, followed by bus commuters, cyclists, walkers, and train commuters (Chertok, Voukelatos, Sheppeard, & Rissel, 2004). Bus commuters were noted to having the highest exposure to levels of NO_2.

Although the concentration of contaminants in air breathed was lower for those using active transport, Bigazzi & Figliozzi (2014) noted that those using active transport had higher inhalation rates, and longer exposure so the total dose was higher. In general, modal comparison studies tend to give inconsistent results, since results are dependent on specific details of the routes analyzed (Bigazzi & Figliozzi, 2014).

However, even where the dose of contaminants is higher, the health risk of that exposure may be small compared to other health benefits. A study using data from the Netherlands that found increased health risk related to exposure to contaminants concluded that the benefit of gained life-years from increased physical activity were nine times larger than the lost life-years from exposure to contaminants (de Hartog, Boogaard, Nijland, & Hoek, 2010).

Reduced noise

Noise exposure, and in particular traffic-related noise, has been associated with a number of health impacts including cardiovascular disease, (Curran et al., 2013), annoyance (Miedema & Oudshoorn, 2001), sleep disturbance and myocardial infarction (de Nazelle et al., 2011). An issue for the road traffic studies is how much of the effects can be attributed to noise or to air pollution. This confounding effect was addressed in a review study which concluded that there was an independent effect of noise and air pollution on cardiovascular diseases (Tétreault, Perron, & Smargiassi, 2013).

Currently, no exposure-health relationships have been derived specifically from travel-time exposure studies. If noise deters walking and cycling, then the impact on physical activity may reflect an indirect effect of noise on health (de Nazelle et al., 2011).

Traffic injuries

Pedestrians and cyclists face a greater risk of injury or death due to traffic collisions than motor vehicle users (Elvik, 2009). People who walk and cycle are at increased risk of injury or death as a result of collisions with motor vehicles, when compared to people driving in card or using public transit (Toronto Public Health, 2015c). In 2013, Toronto had 63 fatal collisions: 40 pedestrians died, 7 drivers, 7 motorcyclists, 5 passengers, and 4 cyclists (City of Toronto, Traffic Safety Unit, 2013). This in spite of only about 9% of total trips by residents being walking or cycling, based on 2011 data (Data Management Group, 2011).

Increases in cycling and walking have been shown to reduce risks for all active travelers. Motorists are more likely to drive more cautiously when there are more active commuters – a "safety in numbers" effect (Toronto Public Health, 2015c). Analysis of collision data found that doubling of people walking would reduce the risk to each individual walker by approximately one-third (34%) (Jacobsen, 2003). The variation in risk rates from different countries with different levels of bicycle use are shown in Figure 3. Countries with higher cycling mode share tend to have fewer injuries and fatalities than those with lower cycling mode share (Pucher & Buehler, 2008).

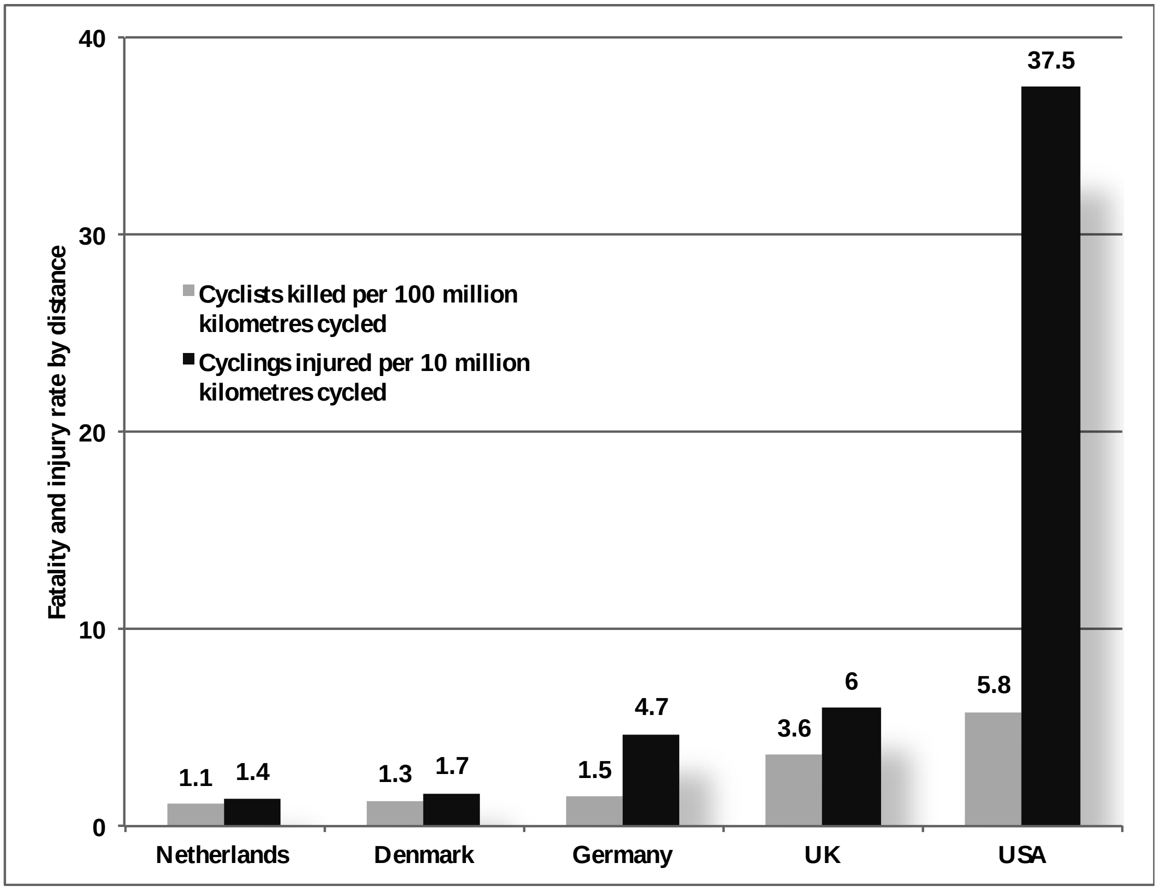

Figure 3 Fatality rates and non-fatal injury rates in the Netherlands, Denmark, Germany, United Kingdom and United States in 2004-2005 (Pucher & Buehler, 2008)

The "safety in numbers" effect is also likely influenced by the fact that cities with more pedestrians and cyclists often have a transportation infrastructure that has been designed with pedestrian and cyclist safety in mind (Toronto Public Health, 2015c). Interventions that can improve cycling and pedestrian safety include traffic calming to reduce vehicle speeds, separation between cars and cyclists or pedestrians (e.g. bike lanes and sidewalks), and traffic signaling phases that accommodate pedestrians and cyclists. Traffic calming has been found to reduce traffic injuries by 15% to 25% (Elvik, 2001), and can also enhances the perception of safety, which further encourages more cycling and walking.

Public transportation

Compared to private car, public transport has a larger carrying capacity. Subways are unaffected by road traffic congestion, and bus schedules can be flexibly arranged to enable multiple buses to travel the same route simultaneously in response to peak times (Parikesit & Susantono, 2012). However, public transport may not be as attractive for local residents as private cars because it is less flexible and can take longer to reach one's destination. These problems can be counteracted by creating priority systems for public transport for traffic lights and building quality bus corridors or priority routes. These approaches have been implemented in several Canadian municipalities including York Region, Winnipeg, and the City of Ottawa, as well as Toronto.

The health benefits of public transportation overlap with many of the benefits of active transportation through increases in physical activity and reduced motor vehicle traffic.

Public transportation and physical activity

The beginning or end of a public transport trip usually involves some walking, and can provide an important opportunity for physical activity (Rissel, Curac, Greenaway, & Bauman, 2012).

A review conducted by Rissel et al. (2012) reported that public transport usage could increase physical activity by 8–33 minutes per day. Research has shown that transit riders self-report more physical activity and healthier body mass indexes (B. B. Brown, Werner, Tribby, Miller, & Smith, 2015). The benefits of increased physical activity are detailed elsewhere in this report.

Health benefits from reduced vehicle emissions

Strategies to reduce GHG emissions from transportation ultimately aim to reduce consumption of the most highly emitting fossil fuels.

As such, the majority of these strategies also reduce emissions of air pollutants.

Traffic-related air pollution has been linked to various respiratory and cardiovascular outcomes, cancer, and hormonal and reproductive effects. In Toronto, trucks and cars account for 42% of premature deaths and 55% of hospitalizations of pollution-related health impacts (Toronto Public Health, 2014a).

Traffic-related air pollution has been shown to contribute to morbidity and mortality linked to respiratory, cardiovascular, reproductive, and neuro-developmental effects (de Nazelle et al., 2011; HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010). One review reported "suggestive but not sufficient" evidence that traffic-related air pollution contributes to cardiovascular mortality, cardiovascular morbidity, onset of childhood asthma, and exacerbation of respiratory symptoms in adults (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010). Others have been more definitive. For example, Chen et al. (2013) found "traffic-related air pollution at relatively low concentrations in Ontario was associated with increased mortality from cardiovascular disease". Bowatte et al. (2015) conducted a systematic review and meta-analysis of birth cohort studies on traffic-related air pollution and asthma and allergies and concluded that exposure to traffic-related air pollution was related to asthma and allergic diseases, in spite of the observed variability observed across studies.

Vulnerability and risk related to air pollutants are not uniform. Those with pre-existing illnesses, including heart disease, asthma, chronic obstructive pulmonary disease, obesity and diabetes; and young children, the elderly and pregnant women, are especially susceptible (Mowat et al., 2014). In regard to asthma and acute bronchitis, children are particularly at risk (Toronto Public Health, 2014a).

Exposures to traffic-related emissions have been found to be higher closer to busy roads and highways, compared to background levels elsewhere. The impact of highway emissions on air quality has been found to be observable up to 300 m downwind (Jeong et al., 2015). This is especially concerning for cities including Toronto. Half of all Torontonians live within 250 m of at least one major roadway, ranging from 10-lane highways to four-lane streets with steady traffic (McMahon, 2015). An assessment for Toronto found that NO_2 was significantly associated with increased ischemic heart disease risk, and that living near major roadways and highways increased the risk of heart disease (Beckerman, et al., 2012). Studies have also found that children living near major highways are at higher risk of developing asthma and reduced lung function (Brugge, Durant, & Rioux, 2007).

Although reducing vehicle emissions is important, studies have found that health benefits are drastically augmented when coupled with transport-specific behavioural programs that increase mass transit use and active transportation. In a modeling assessment for London, Woodcock et al. (2009) found that a sustainable transport policy, that incorporated both lower-carbon vehicles and encouraged active transportation, achieved the greatest health benefits. Per million people, 17 premature deaths and 160 disability adjusted life-years (DALYs) were prevented by just low-carbon vehicle policies, compared to the 541 premature deaths and thousands of DALYs prevented per million people in the sustainable transportation scenario (Table 15).

Table 15 Annual health effects (per million people) as a result of transportation policies in London compared with the business as usual case, UK.

	Lower-carbon emission motor vehicles	Increased active transport	Towards sustainable transport
		Physical activity	
Premature deaths	0	–528	–528
YLL	0	–5496	–5496
YLD	0	–2245	–2245
DALYs	0	–7742	–7742
		Air pollution	
Premature deaths	–17	–21	–33
YLL	–160	–200	–319
YLD	0	0	0
DALYs	–160	–200	–319
		Road traffic accidents	
Premature deaths	0	11	11
YLL	0	418	418
YLD	0	101	101
DALYs	0	519	519
		Total	
Premature deaths	–17	–530	–541
YLL	–160	–5188	–5295
YLD	0	–2144	–2144
DALYs	–160	–7332	–7439

Notes: The "Towards sustainable transport" scenario is the combination of the lower-carbon emission motor vehicles and increased active transport scenarios.

SOURCE: (Woodcock et al., 2009).

Transportation summary and conclusions

Transportation is a very significant source of GHG emissions in Toronto. It is also a very significant source of other air pollutants, and of noise. Toronto's most recent GHG emissions inventory indicates that a notable feature of the TransformTO project will be to improve the Toronto transportation emission inventory. From a health perspective, it will be desirable to ensure that this new modeling work addresses other contaminants in addition to GHGs. NO_x emissions were considered in earlier inventories, but were not included in the most recent (2013) inventory.

Most of the GHG emissions are associated with light duty vehicles, and these can be expected to decline as the vehicle stock turns over and the impact of already enacted regulations becomes visible. Another contributing factor will be the province's push to encourage adoption of electric vehicles, which do not have tailpipe emissions (Ontario Ministry of the Environment and Climate Change, 2016).

The transportation sector is a significant source of air pollutants, and there are credible studies identifying the health impacts related to those air pollutants. Heavy vehicles contribute disproportionately to those emissions. Other cities have taken measures to promote the more rapid turnover of the vehicle stock, and limit exposure to emissions from heavy vehicles through incentives or the introduction of low-emission zones.

Progress has been made through regulation on vehicle fuel efficiency and pollutant emissions. In the longer term, we will need to turn our attention to the total number of vehicles on the road and opportunities for deeper emission reductions.

A major focus of urban transportation analyses for GHG reduction and health promotion has been active transportation. There is a rich literature on the benefits (and risks) of active transportation. Benefits are primarily related to health benefits of higher levels of physical activity for the user, and lower vehicle emissions for the broader population. Risks may be increased exposure of users to contaminants or the risk of accidents, though those may be mitigated through design, and the risk of collisions decreases as more people participate in active transportation. A number of analysts have examined the cumulative, net impact on health of increased physical activity and have concluded that the benefits outweigh the risks by a significant margin.

Buildings

Even with a growing population and declining average number of persons per household (City of Toronto, 2012a), Toronto's emissions of GHGs associated with buildings are declining. But there remains substantial mitigation potential: if implemented, already-established best practices and technologies could drastically reduce energy use over the next few decades. Evidence suggests that energy savings of up to 90% are achievable through deep building retrofits (Scovronick, 2015).

In 2013, natural gas use in buildings accounted for about 38% of the total GHG emissions reported in the city's inventory (see Table 7), though it accounted for a smaller percentage (about 15%) of the estimated NO_x emissions because natural gas creates relatively less NO_x when burned. The vast majority of the electricity leading to GHG emissions is also building related (11% of reported GHG emissions), for a total of almost half the reported emissions. Again the air quality impacts are relatively small (less than 1% of NO_x based on the limited data available). As shown in Table 4, only about 10% of electricity generation in Ontario is from fossil fuel combustion (Independent Electricity System Operator, 2016), and most of that generation is outside of the city. Only the Portlands Energy Centre, a peaking natural gas facility, is inside the city.

Many strategies for reducing GHG emissions from buildings focus on reducing energy consumption. Strategies include:

- Reducing the amount of space required for living and working, and in particular the building area exposed to the weather;
- Retrofitting existing buildings to dramatically reduce energy requirements;
- Ensuring that new buildings are highly energy efficient – the most advanced buildings are net energy generators;

- Changing the energy sources used to meet the needs of buildings to lower carbon sources.

These measures have potential benefits for health, including:

- Reducing the releases of criteria air contaminants associated with burning fossil fuels
- Improving ventilation and reducing exposure to indoor air contaminants
- Ensuring that indoor temperatures stay within a healthy range.

Other strategies focus on fuel switching and on-site generation.

Strategies to reduce energy consumption in buildings

Here we describe several general strategies for reducing energy consumption, and therefore GHG emissions, in existing and new buildings. The focus here is on the GHG and health implications of these strategies generally, rather than particular approaches and technologies for retrofitting existing buildings and designing new buildings.

Reducing space requirements

Denser dwellings tend to require less energy, and thus have fewer associated GHG emissions. In Ontario, single family detached homes accounted for 55% of the housing stock in 2013 (Natural Resources Canada, 2016), but used a disproportionate 73% of energy for space heating (Canada, 2016). In contrast, apartments accounted for 29.6% of the housing units (Natural Resources Canada, 2016) and only 13.5% of the space heating energy demand (Canada, 2016). Almost 30% of dwelling units in the Toronto Metropolitan Area are apartments (Statistics Canada, 2013)

There is already a trend towards small homes and more efficient use of office space. Bank towers have reduced the space per employee from 24 m^2 to 14 m^2 over the last 10-15 years (Perkins, 2013). According to a survey conducted by the Canadian Home Builders Association, the average new home size has shrunk to approximately 176 m^2 from 214 m^2 in the mid-2000s, and is forecasted to become even smaller (Hopper, 2012). Reasons cited include a shortage of land to develop, cost concerns of buyers, and more efficient layouts. Reducing space requirements can reduce GHG emissions without impacting health, if done to reasonable levels that do not introduce crowding.

Retrofitting existing buildings

The benefits of building retrofits go beyond increasing energy efficiency and reducing GHG emissions. When planned with health considerations in mind, energy efficiency retrofits can increase ventilation, improve thermal comfort in winter and summer, reduce wetness and improve quality of life for residents.

Toronto has a diverse building stock, including single-family dwellings, row houses, low-rise apartments, high-rise apartments, large and small office buildings, large and small retail outlets etc. Most GHG emissions from buildings result from the combustion of natural gas for space heating and water heating. The breakdown of natural gas use by building type in Toronto is in Table 16. The table indicates that for all types of buildings shown, natural gas use for space heating is greater than for water heating.

Table 16 Estimated natural gas use (TJ) for the Toronto building stock in 2004

	Low-rise residential	Apartments	Commercial	Total
Space heating	46,145	21,687	51,676	119,508
Water heating	17,503	8,226	9,119	34,848
Total	**63,648**	**29,913**	**60,795**	**154,356**

SOURCE: (Sugar & Kennedy, 2012)

There is a lack of detailed district-wide information on consumption by building floor area, type, age, and use. Much of the available data exist in different formats and databases but are not brought together in such a way that they can inform strategic decision making for policy development (Sugar & Kennedy, 2012).

Buildings of similar size located in similar climates have been shown to have significantly different energy use, likely due to varying energy efficiencies of the building envelope (Scovronick, 2015). The strategies to be employed for retrofitting, and the energy savings (and GHG reductions) that can be expected will vary by building type, age and use.

As an example of the potential that may be possible, a recent study (Jermyn & Richman, 2016) of Toronto single family homes examined three different archetypical homes and estimated energy savings possible from deep retrofits, involving the building envelop and heating, ventilation, and air conditioning (HVAC) systems, under two different scenarios. Under the first scenario (targeted reduction of use to 75 kWh/m^2/a), savings of energy for heating and cooling in the three archetypes ranged between 64 and 67%. In the second scenario, based on a passive house standard of 25 kWh/m^2/a, savings of 88-89% of space conditioning energy use were realized.

There are also significant opportunities in multi-residential buildings. Savings in Toronto high-rises of over 50% have been posited (Sugar & Kennedy, 2012), though estimates of 30% are more common (Canada Mortgage and Housing Corporation, 2004; Hepting & Jones, 2008; Sustainable Infrastructure Group, University of Toronto, 2010). A study for New York City estimated that overall energy savings in buildings (of all types) of 60% from efficiency measures are feasible (Wright, Leigh, Kleinberg, Abbott, & Scheib, 2014).

The City of Toronto's Tower Renewal Program aims to drive broad environmental, social, economic, and cultural change by improving Toronto's concrete apartment towers and the neighbourhoods that surround them. One of the key activities of this program is enabling and supporting retrofits to existing buildings to improve energy efficiency and quality of life for residents (City of Toronto, 2014b). The Toronto Atmospheric Fund and the Toronto Community Housing Corporation (TCHC) are also undertaking a joint program to implement energy efficiency retrofits in some TCHC buildings, including consideration of health and quality of life (Toronto Atmospheric Fund, 2016).

New buildings

Most of the building stock that will be around in 2050 has already been built, but there will be new buildings, and these can be much more energy efficient and produce fewer GHG emissions, either directly or indirectly. Houses (Valentina, 2016), multi-family residences (Hanes, 2012) and commercial buildings (Applegath, 2014) can all be designed to be zero energy buildings, or to generate more energy over a year than they use, through a range of strategies including: proper orientation of the building and fenestration (arrangement of windows and other openings), sealing of the building envelope, efficient equipment, and on-site energy generation (typically solar).

Healthy buildings and healthy temperatures

In Toronto, there are almost 1,200 older apartment towers (built between 1945 and 1984) with eight or more storeys, that are home to roughly 500,000 people (City of Toronto, 2014b). The majority of older apartment buildings do not have central air conditioning. In 2011, Toronto Public Health mapped levels of heat vulnerability in Toronto and found that areas of high vulnerability tend to overlap with clusters of large apartment buildings built prior to 1986 (Toronto Public Health, 2015d).

The health impacts of extreme heat include heat stress, heat stroke, morbidity and mortality. Seniors and low-income residents are especially vulnerable to heat stress, likely due to poorer quality housing, limited access to air conditioning, and the increased likelihood that they suffer from pre-existing illness (Toronto Public Health, 2014b). Current heat conditions are estimated to cause 120 premature deaths per year in Toronto, and could double by 2050 and triple by 2080 (Toronto Public Health, 2005).

Toronto Public Health recently indicated that, based on the available health information, there is a need to better protect residents from extreme heat, and the feasibility of implementing a health-based maximum indoor temperature standard of 26 degrees Celsius for rental multi-unit residential buildings should be explored. This strategy is one component of a multi-pronged approach to reducing the health risk to vulnerable populations from extreme heat (Toronto Public Health, 2015e).

As a result of climate change, Toronto is also expected to be at an increased risk of more severe or prolonged heat events with three-day heat waves increasing by five times by 2050 (City of Toronto, 2012b). Toronto Public Health inspectors have also found that indoor temperatures can be extremely high (~32-39C) (Toronto Public Health, 2015d). Addressing high indoor temperatures is crucial. Climate change mitigation and adaptation measures for buildings should be considered in a collective approach that minimizes GHG emissions and reduces health risks (Vardoulakis et al., 2015).

Challenge of the urban heat island effect

Urban areas have average temperatures 3-5 C higher than surrounding regions. The prevalence of dark surfaces that absorb heat, such as buildings and streets, combined with heat sources such as vehicles, and the absence of trees and green space, cause the urban environment to heat up. This process is called the urban heat island (UHI) effect. The UHI effect can have a significant impact on health and air quality, as each degree Celsius increase in temperature can result in a 5% increase in smog formation (City of Toronto, Energy Efficiency Office, 2007).

Table 17 compares the health benefits potential (hazard reduction potential) of some measures to mitigate against the UHI effect. The table indicates on a city scale, treed greenspace is effective in mitigating UHI outdoors. This needs to be combined with cooling strategies in the buildings in order to significantly reduce the hazard of extreme heat indoors.

Table 17 Classification of passive cooling measures' potential to mitigate UHI, where (+) has small, (++) has medium, (+++) has high, (0) has null, and (-) has negative effectiveness

Measures	Health co-benefits potential	
	Outdoors	Indoors
City scale (pavement and urban green space)		
Cool pavements	+	+
Trees	++	+
Grass	+	0
Building scale (roofs)		
Cool roof	+	+
Green roof	+	+ (0)
Room scale (passive and active cooling)		
Overhangs & shutters	0	++
Curtains	0	+
Night ventilation	0	++ (+)
Vapour compression AC	-	+++
Absorption based AC	-	+++
Evaporative cooling	0	++

SOURCE: (Buchin, Hoelscher, Meier, Nehls, & Ziegler, 2016)

Reducing the UHI effect also has profound impacts on energy use. Electricity demand tends to decline as temperatures increase to levels where heating is not required (e.g. winter to spring). Less energy is needed to run furnaces and other heating loads, and warmer weather implies longer hours of sunlight so lights are on for less time. However, energy demand dramatically increases as air conditioners begin to be turned on (City of Toronto, Energy

Efficiency Office, 2007), and now annual peak energy consumption occurs in the summer.

Energy efficient indoor cooling strategies

Air conditioning can mitigate indoor heat stress but requires considerable energy consumption. This brings with it implications of cost, especially for low income households, and additional GHG emissions. Extensive use may also contribute to the UHI effect, as heat taken from inside is exhausted to the outside.

In a 2010 survey, 15% of Toronto respondents reported not having air conditioning in their home whereas 35% of low-income respondents reported not having air conditioning in their home (Toronto Public Health, 2015d). Toronto Public Health is concerned about the disproportionate impact of extreme heat and electricity costs on vulnerable residents living in older apartments, as many of these buildings are in neighbourhoods that show increased poverty, isolation, social need and health risk.

Few of the apartments in Toronto that were built before 1986 have central air conditioning, and most units do not have window or portable air conditioners. As the duration and intensity of heat waves increases with climate change, that demand for air conditioning will grow, and with it demand for electricity for cooling. Meeting increased future demand for cooling would increase peak electricity demand significantly. There is a need to identify strategies to cool buildings using the least possible energy.

There are passive and energy-efficient options to address indoor extreme heat without the negative environmental impacts of inefficient air conditioning. Some examples of passive cooling strategies at the neighbourhood and building scale are shown in Table 18. Passive and energy-efficient cooling strategies for inside buildings are available, and merit further assessment.

Table 18 Examples of passive cooling options and findings related to energy, temperature and health

Option	Finding	Source
Mature trees	Mature trees around the average home reduce air conditioning demand by 25-40%	City of Toronto, Energy Efficiency Office (2007).
Urban green space	Urban greenery is positively associated with physical health (e.g. healthy weights and birth outcomes, reductions in cardiovascular disease and all-cause mortality), mental health (e.g. improvements to stress, anxiety, depression, self-reported mental health), and well-being (e.g. self-reported well-being and health).	(Toronto Public Health, 2015b)
Cool pavements	Materials that have high albedo (solar reflectance) maintain cool surfaces. These "cool" materials lower surface temperatures and the amount of heat stored in surfaces.	United States Environmental Protection Agency (2008)
Cool roofs	An assessment for two Chicago neighbourhoods, found that a 0.10 average increase in albedo (equivalent to a 0.40 roof albedo increase for a roof area plan fraction of 0.25) will reduce peak summer daytime temperatures by 0.5 C under clear skies.	Krayenhoff & Voogt (2010)
	Cool coloured roof averaged an 8 C cooler interior than an asphalt one	Bozonnet, Doya, & Allard (2011)

In addition to consuming electricity, over 95% of commercial and residential air conditioning units in Canada operate on hydrochlorofluorocarbon (HCFC) refrigerants (CRACCA with

Environment Canada, n.d.). HCFCs are ozone-depleting substances, many of which have high global warming potentials: R-22 has a GWP of 1810 times higher than CO_2 (UNEP, n.d.). The Canadian government has adopted the following phase-out plan for HCFCs based on the terms of the Montreal Protocol (CRACCA with Environment Canada, n.d.):

- **January 1, 2010 -** no new R-22 equipment manufactured or imported;
- **January 1, 2015** - annual allowable amount of HCFCs reduced by 90%;
- ***January 1, 2020*** - annual allowable amount of HCFCs reduced by 99.5% except HCFC-123 which can be imported or manufactured until 2030 to service large air conditioning units (chillers) under the remaining 0.5% allowance. No new HCFC equipment to be manufactured or imported;
- ***January 1, 2030*** - HCFCs no longer permitted to be imported or manufactured.

Reducing emissions of these powerful GHGs is an important component of a GHG mitigation strategy.

Healthy buildings and healthy indoor air

As described above, improving buildings can be an effective means to reduce energy use required to maintain comfortable indoor temperatures, reduce GHG emissions, help keep buildings dry and improve quality of life. Retrofitting existing buildings and improving the design of new buildings to reduce energy consumption can also improve indoor air quality.

Tight thermal envelopes can be especially effective in colder climate cities like Toronto's, to minimize winter heat loss through joints, walls, foundations, and ceilings (Röbbel, 2011). Improvements to the building envelope can also reduce the use of air conditioners and the energy they require.

Some of the potential health implications of more efficient buildings are shown in Table 19. The table outlines some health benefits. It also indicates that retrofits need to be planned with health in mind to prevent or mitigate any unintended consequences. For instance, ensuring adequate ventilation can prevent potential health consequences of air sealing and ensure adequate fresh air. In the table, ventilation is identified as both a direct effect and an action: the former with increased health risk and the latter with a health benefit. Efficient buildings, whether new buildings or retrofitted buildings need to address indoor air quality.

Table 19 Examples of improvements to increase the efficiency of buildings, direct effects and potential health impacts requiring mitigation

Action	Direct effect	Potential health impact
Improve building envelope	Regulate indoor temperature	Reduce heat stress and risk of heat-related stroke, cold-related disease risks (e.g. respiratory infections), and improved mental health
Insulation and air sealing	Reduce dampness	Reduce risks such as stroke, asthma, allergies and respiratory disease
Air sealing	Lack of ventilation	Increased infection transmission, CO poisoning, neurological sequelae from indoor air pollution
Improved ventilation	Reduced exposure to building materials off-gassing and other indoor air pollutants	Reduced risk of airborne transmission, of asthma related to dust and mites, of microbial infections

ADAPTED FROM (ROBBEL, 2011)

A recent meta-analysis of 36 studies of the relationship between energy retrofits and health found a modest but positive relationship between energy retrofits and health (Maidment, Jones, Webb, Hathway, & Gilbertson, 2014). Some opportunities for health advances and GHG reductions also lie in the clean, low-carbon improvements to low-income and community housing (Röbbel, 2011). Positive health impacts were found to be more pronounced for retrofitting households of people with low incomes (Maidment et al., 2014), possibly because those buildings offered greater opportunity for improvements.

As buildings are improved to be more energy efficient and less leaky, indoor air pollution is a risk: one that can often be addressed through good ventilation. The Ontario Building Code (2012) in recent years has required homes to be more tightly sealed, and concurrently requires that mechanical heat recovery ventilation systems be designed and installed (Ontario, 2014). These can substantially increase ventilation rates, reducing exposure to pollutants from indoor sources, if properly installed, operated, and maintained, and from outdoor sources if air filtration is provided (Shrubsole et al., 2012).

A number of studies of health impacts of early work on building tightening showed negative health impacts, but now addressing ventilation is a standard part of building retrofits (Wilson et al., 2013). To address some of the limitations of the literature, Wilson et al. (2013) measured improvements to health in 248 households after retrofits of buildings in Chicago, Boston and New York. They used structured telephone interviews that addressed respiratory, cardiovascular and mental health. In general, the status of health reported improved, including reduced sinusitis and reduced allergy medication. There were not noticeable differences in indoor concentrations of standard contaminants including NO_2 and CO in the subset of buildings sampled; concentrations were low before and after the retrofit work. They did find increases in some asthma symptoms after the retrofits, possibly because dampness was not addressed, possibly from re-entrainment of aeroallegens in ductwork.

Table 20 summarizes the benefits of sample indoor air quality improvement measures that are applicable to residential buildings.

Table 20 Adaptation measures to improve indoor air quality

Adaptation measure	Impact on indoor air quality	Source
Remove indoor sources		
Have a qualified service technician inspect and clean your fuel-burning appliances, furnace, vent pipe and chimney flues once a year.	Reduce indoor concentration of CO and NO2	City of Toronto (n.d.)
Install at least one carbon monoxide detector on every level of the home, especially outside sleeping areas; ensure that CO detector meets Ontario Fire Code and Ontario Building Code		
Use products with zero VOC emissions	Reduce VOC emissions from building materials and consumer products	Live Green Toronto (n.d.)
Ventilate effectively		
Optimum location of ventilation inlets away from outdoor pollution sources	Minimize ingress of outdoor air pollutants	Kukadia and Hall (2004), Zero Carbon Hub (2012)
Tighten building envelope with MVHR (installed, operated and maintained properly)	Prevent ingress of oudoor air pollutants	Wilkinson et al. 2009); Shrubsrole et al. (2012); Taylor et al. (2013); Gens et al. (2014)
	Remove indoor air pollutants generated from indoor sources	
Air filtering in mechanical ventilation systems	Remove a portion of allergens, particulate, and ozone	Weschler (2006)

ADAPTED FROM (Vardoulakis et al., 2015)

Outdoor pollutant concentrations are a major contributor to indoor air pollution, and tightening the building envelope can minimize ingress of air pollution to the home. An analysis of the impact of a number of scenarios for improving building performance in Toronto on exposure to particulates from outdoor concentrations indicated that there were health benefits. The authors indicated that in their opinion, on the sole basis of outdoor $PM_{2.5}$ reduction for most cases, these benefits alone did not justify the cost of the measures (Zuraimi & Tan, 2015). The exception was replacing conventional air filters with highly efficient filters. Although the study considered the economic value of a range of health outcomes related to PM exposure, it did not consider other possible health benefits, such as reduced exposure to ozone or volatile organic compounds.

Eliminating smoking indoors may be more effective than improving building performance to reduce indoor PM concentrations. Chen & Zhao (2011) reported that $PM_{2.5}$ indoor concentrations are approximately three times greater than outdoor concentrations in the presence of indoor smoking. A recent assessment of the exposure to tobacco smoke in renovated low-income, high-rise buildings found that retrofitting in most cases led to reductions in exposure (Fabian et al., 2016).

Ventilation is an effective mechanism for removal of many air pollutants, including VOCs, NO_x and radon. In fact, the National Building Code of Canada (2010) requires the installation of measures to prevent radon ingress in new and extended/refurbished dwellings, and requires that engineers and designers consider radon protection in their designs (Dunn & Cooper, 2014). The Ontario Building Code (2012) is subject to radon prevention measures in the construction of schools and other large buildings (Dunn & Cooper, 2014).

Common indoor air pollutants, their source and their potential health impacts are presented in Table 21.

Table 21 Indoor air pollutants, sources and health impacts

Indoor air contaminant	Source	Health impact	Reference
Particulate matter (PM)	Indoor combustion (wood burning, cooking, smoking)	Increased respiratory illness (wheezing, cough, including asthma) and COPD	(Géhin, Ramalho, & Kirchner, 2008; Orozco-Levi et al., 2006; Simoni et al., 2002; Triche et al., 2005; Weisel, 2002)
	Passive smoke	Higher risk of coronary artery diseases, lung cancer, respiratory diseases and stroke	(US-DHHS, 2006).
Volatile organic compounds (VOCs)	Product off-gassing from building materials, furniture, paints, and consumer products; tobacco smoke and other combustion sources	Include irritation to the eyes, nose, and throat, headaches, nausea, and damage to the liver, kidney and central nervous system	(United States Environmental Protection Agency, 2016)
	Consumer products	Wheezing, vomiting, and diarrhea and headache among infants and their mothers.	Farrow, Taylor, Northstone, & Golding (2003)
Nitrogen dioxide (NO_2)	Combustion	Children with asthma or at risk of developing asthma have been shown to be especially	Vardoulakis et al. (2015).

Indoor air contaminant	Source	Health impact	Reference
		susceptible to various respiratory symptoms (e.g. wheeze) or lung function indices	
Carbon monoxide (CO)	Combustion	Health effects ranging from headache and dizziness, nausea and sickness to coma and death	Vardoulakis et al. (2015).
	Problem gas appliance installation	High but non-lethal exposure can result in long term neurological effects	Croxford, Leonardi, & Kreis (2008).
Ozone (O_3)	Outdoor air, interaction with NO_x	Reduced lung function, exacerbated chronic respiratory illness, increased respiratory hospital admissions and all-cause mortality	Vardoulakis et al. (2015).
Radon	Soil gas	Based on a compilation of seven North American case-control studies, the risk of lung cancer increased by 11% per 100 Bq/m3 increase in measured radon concentration.	Krewski et al. (2006)

Retrofits for energy efficiency can have diverse health benefits including those resulting from healthy temperatures and improved indoor air quality. These findings emphasize the need to ensure that health related factors are considered when undertaking energy saving and GHG reducing measures in buildings.

Fuel switching and on-site generation

GHG emissions from buildings result from the use of natural gas, primarily for space heating, and from the use of electricity from the grid for lighting, equipment, and primarily cooling. By shifting from natural gas to electricity or renewable sources of energy, or by shifting from electricity to renewable sources of energy, GHG emissions may be reduced.

There are technologies for switching space heating from natural gas to electricity, including various types of heat pumps, such as air source, ground source and hybrid, which use natural gas on very cold days. The reductions in emissions of GHGs and conventional air contaminants, and lifecycle cost, should be assessed for Toronto.

Buildings can be potential sites for small-scale renewable energy generation by fitting solar panels or installing district heating systems (Röbbel, 2011). Significant local health benefits can be realized for improved air quality and energy security associated with shifts to renewable energy and efficiency measures (Scovronick, 2015). Although renewable energy generation reduces air pollution, renewable technology should be installed correctly to avoid overheating and other safety risks like electrification to maximize health impacts (WHO, 2014).

Combined heating and power

Combined heating and power (CHP) systems generate electricity near the site of use and capture the waste heat for space heating or water heating. CHP reduces wasted energy by almost half and can deliver energy with efficiencies greater than 90%, while significantly reducing emissions per kWh compared to using the same fuel for generating both useful heat and electricity in separate systems (Ellamla, Staffell, Bujlo, Pollet, & Pasupathi, 2015). In this way, CHP systems can reduce the emissions resulting from power production. Different building types may be more or less likely to reduce emissions with CHP systems based on the electrical and thermal needs of the building (Mago & Smith, 2012).

Renewable energy

Renewable energy sources for electricity are generally clean sources of electricity, compared to electricity derived from fossil fuels, and have lower life cycle human health impacts (Hirschberg et al., 2016). From the perspective of Toronto's scope 2 emissions analysis, renewable technologies may be considered virtually carbon-free: life-cycle carbon emissions are upstream of the user. Table 22 summarizes the implementation potential for renewable energy technologies in Toronto.

Table 22 Toronto's renewable energy potential

Technology	Application	Energy	Potential (relative to energy used in application)	Development of the Resource (level of impact on sector)			Limitations & Barriers
				Short term	Medium term	Long term	
Photovoltaic	Residential (existing)	Electricity	Medium	Low	Medium	High	
	Residential (new) – zero energy homes		High	Low	Low	Medium	Number of new homes built
	Commercial Roof		Medium	Low	Low	High	
	Commercial – Building Integrated		Medium	Low	Low	Medium	Number of new building built
	Solar Park		Low	Low	Medium	Low	Lack of large open spaces in Toronto
Solar Thermal	Residential Domestic Hot Water	Thermal	High	Medium	High	High	
	Commercial Hot Water		Medium	Low	Medium	High	
	Pool Heating		High	High	High	High	
	Space Heating – Residential (combi)		Medium	Low	Low	High	
	Make Up Air – Commercial/Industrial		Medium	Low	Medium	High	Limitation of new industrial buildings being built in Toronto
	Air Conditioning	Electricity (Displacement)	High	Low	Low	High	
Passive	Residential	Thermal	Medium	Low	Low	Medium	Number of new homes built
	Commercial – Day Lighting	Electricity	Medium	Low	Low	Medium	Number of new buildings built
Wind	Wind Farms/Large Turbines	Electricity	Low	Low	Medium	Medium	Access to waterfront or in the lake
	Residential		Low	Low	Low	Low	Low resource in the city
	Wind in the Build Environment		Low	Low	Low	Medium	Technology is only in very early stage of development
Hydro	Run of River, Impounded	Electricity	Low	Low	Low	Low	Few rivers in Toronto
	Rain Water Catchments		Low	Low	Low	Medium	Height and roof area of high buildings
Geo Energy	Residential	Cooling (displacement of electricity), Heating (thermal)	High	Medium	High	High	Access to ground space
	Commercial		High	Medium	High	High	
	Community Energy Systems		Medium	Low	Medium	High	Need for integrated community energy planning
	District Energy Systems (Enwave)		Medium	Low	Medium	High	Access to deep water
Bio Energy	Waste Water	Co-gen	Low	Medium	Medium	Medium	
	Solid Waste		Medium	Low	Medium	Medium	Landfills are not in Toronto – need to capture in waste stream
	Bio Mass		Low	Low	Medium	High	Public Perception of energy from waste
	Bio-Gas/ Bio Fuels		High	Low	Low	High	Import from agricultural communities

SOURCE: (City of Toronto, Energy Efficiency Office, 2007)

The health benefits of renewable energy are well known. A transition to renewable energy production may also lead to a reduced burden of occupational injuries and diseases (e.g. respiratory diseases and cancers) commonly associated with fossil fuel extraction and use. However, the upstream occupational health issues associated with solar photovoltaics in particular are not well understood (Bakhiyi, Labrèche, & Zayed, 2014), and require additional study. Renewable energy technologies may introduce some new occupational risks, such as exposure to nanoparticles or hazardous chemicals in certain types of solar panel production, which have been linked to cancer (Scovronick, 2015). The broader population health may also be affected through potential exposure to toxic waste products from discarded materials (Portier, et al., 2010). To fully realize the health benefits of renewable energy technologies, these risks need to be assessed and mitigated as the industry grows and develops (Scovronick, 2015). The life cycle GHG and health benefits of renewable energy, and any risks, should be considered relative to those associated with more conventional sources of energy.

Deep-lake cooling

Other renewable energy opportunities specific to Toronto include the potential for increasing use of deep lake cooling for building space conditioning.

Enwave's deep water cooling system stretches into Lake Ontario and provides passive cooling by using naturally cold water as a heat sink in a heat exchange system (Newman & Herbert, 2009). An assessment of the GHG-reduction potential of extending the system to the Ryerson University campus estimated that it would result in an 89% reduction of air conditioning related GHG emissions (Fung, Taherian, Rahman, & Selim, 2015).

Enwave serves only the downtown core's district energy system and generates cooling for downtown office buildings in the summer primarily with deep-lake water cooling. The deep-lake cooling capacity of the system can potentially be expanded by four times by chilling blocks of ice during nightly low periods using the cooling capacity of lake water to enhance the efficiency of the compressors, and then using the ice during the day for heat transfer (City of Toronto, Energy Efficiency Office, 2007). This technology is already well developed and used in Chicago, where the city centre is cooled by an ice storage system. Some individual buildings in the Greater Toronto Area, including the MEC store in Burlington, have similar technology, using nighttime baseload electricity to produce ice that is then used during the day to cool the building (Mountain Equipment Co-op, 2016).

Buildings summary and conclusions

Natural gas is widely used in buildings, primarily for space heating. This use is a major source of GHG emissions in the city, even though natural gas is the cleanest burning fossil fuel. From a GHG perspective, this sector is a particular concern given that the building stock turns over slowly, and most of the buildings standing today will remain standing in 2050.

Inadequacies in some buildings are responsible for a range of health impacts related to poor indoor air quality, and the inability to maintain comfortable and healthy temperatures. There is a large opportunity to address these problems concurrently with upgrading the energy efficiency of the buildings. When upgrading for energy efficiency, the Ontario Building Code requires that proper ventilation be provided to avoid impacting indoor air quality. Studies of the retrofitting of older buildings generally show an improvement in air quality and health, but not always. Further, some of these studies (e.g. Wilson et al., 2013) found health benefits that were not suggested by measuring air quality. These analyses suggest that as the City continues to undertake and support major building energy-efficiency upgrades, it should continue to incorporate health considerations into the design of these programs.

There are also opportunities to reduce use of natural gas in buildings by switching to other energy sources, whether electricity (e.g. for heat pumps) or renewable technologies. An up-to-date assessment of the potential for these technologies in Toronto would be valuable to decision-makers in this field.

Urban form

The pattern of development and form of a city affect both the quantity of GHGs emitted, and human health. Urban form integrates consideration of transportation and buildings, and has a significant influence over people's transportation needs and choices in daily life.

Compact, walkable, transit-friendly, mixed-use neighbourhoods

Urban form that has walkable, transit-oriented, mixed-use neighbourhoods can reduce the dependence on automobiles and their associated GHG emissions. These sustainable neighbourhood features can also result in health benefits, by encouraging active transportation; mitigating burdens of illness; improving safety; and encouraging healthy diets. These features and associated health benefits are explored below.

Features that encourage active transportation

An important foundation of sustainable, healthy urban form is that it is based on complete streets. Complete streets are those that address the needs of all users and uses, including pedestrians of all ages and abilities, public transit, cyclists, and motorists. Complete streets perform social, cultural, environmental and economic functions, and enable sustainable transportation choices. These features of urban form also promote equity by increasing access to goods and services and removing the financial barrier associated with car use.

Models have been developed to estimate the levels of reduction in vehicle-kilometres traveled, and increases in other travel modes, resulting from measures such as increased density, mixed uses, intersection density and wider sidewalks (de Nazelle et al., 2011).

One metric that assesses the relationship between an action and an outcome is elasticity, which quantifies the association between two variables as a percent change in a dependent variable as a result of a one-percent change in the independent variable. Table 23 shows the estimated elasticity between some neighbourhood design characteristics and transportation choices, specifically transit use, walking, and distance driven per household. As an illustration from the table, if density were to increase by 100%, the probability of walking would be expected to increase by 7%. In general, the elasticities are individually quite low, but become more significant when combined.

Table 23 Estimated elasticity (SD) of transit, walking, and VMT outcomes for neighbourhood design and city infrastructure variables

	Probability of transit use	# of transit trips	Probability of walking	# of walking trips	Distance driven per household
Density	0.08 (0.14)	0.17 (0.15)	0.07 (0.07)	0.14 (0.39)	-0.08 (0.16)
Mixed uses	0.18 (0.16)	0.16 (0.17)	0.26 (0.22)	0.25 (0.28)	-0.05 (0.05)
Intersection density	0.19 (0.05)	0.46 (0.12)	0.32 (0.22)	0.61 (0.70)	-0.16 (0.08)
Sidewalks	0.14 (0.14)	--	0.66 (0.80)	--	-0.01 (0.01)

SOURCE: Estimates reported in de Nazelle et al. (2011), based on estimates by (Ewing & Cervero, 2010)

US studies have found that doubling residential density might reduce the number of vehicle-kilometres travelled by 19% (Cervero & Murakami, 2010). The elasticities between various mitigation options on vehicle-kilometres traveled, based on a review by Kay, Noland, & Rodier (2014) are summarized in Table 24.

Table 24 Summary of influence of transit service, residential density, land use mix, regional accessibility, and pricing, on vehicle kilometres traveled

VKT elasticity with respect to	Range	Studies
Transit service	-0.002 to -0.05 (-0.03 is common)	Metropolitan Transportation Commission (2007), Rodier and Johnston (2002), Rodier et al. (2003), Johnston et al. (2008), Ewing et al. (2008), Cervero and Murakami (2010), Bento et al. (2003)
Residential density	-0.07 to -0.12	Bento et al. (2005), Brownstone and Golob (2009), Fang (2008)
Land use mix	-0.02 to -0.09	Chapman and Frank (2004), Frank and Engelke (2005), Frank and Engelke (2005), Kockelman (1997), Kockelman (1997), Ewing and Cervero (2010)
Regional accessibility	-0.13 to -0.23	Bento et al. (2003, 2005), Cervero and Kockelman (1997), Kuzmyak et al. (2006), Zegras (2010), Ewing and Cervero (2010)
Pricing	-0.15 to -0.22	Deakin et al. (1996), Metropolitan Transportation Commission and Parsons Brinckerhoff (2013), Sacramento Area Council of Governments (2012)

SOURCE: Kay, Noland, & Rodier (2014)

There is local evidence that implementing more walkable infrastructure can have multiple health benefits. Toronto residents who live in more walkable neighbourhoods – compact, well-connected, and mixed-land use communities – make different transportation choices than those who live in less walkable neighbourhoods. Residents in walkable neighbourhoods tend to walk more often, use transit more often, drive less often, drive fewer kilometres each week and have lower body weights (Toronto Public Health, 2012b). Sallis et al. (2009) found that that residents of walkable neighborhoods in the United States spent 32 and 4 more minutes per week of physical activity for transportation and leisure, respectively, than those in low-walkable areas.

Street connectivity (i.e. number of four-way intersections) shortens walking distances and provides multiple paths to reach destinations, and has also been associated with higher levels of transit use and walking, and less driving (de Nazelle et al., 2011). Planning with pedestrians and cyclist in mind can mitigate neighbourhood characteristics that discourage active transport and physical activity. These negative characteristics include environmental barriers (e.g. lack of bicycle trails and walking paths separated from vehicular traffic); unsafe neighborhoods; food deserts (lack of grocery stores offering healthy food); lack of well-connected streets and sidewalks; and lack of accessible transit stops (Heath & Troped, 2012).

Similarly, the availability of public transit influences transportation choices. There is consistent evidence that there are significantly higher levels of walking and public transport use, and less driving, when public transport access points (e.g. stations and bus stops) are closer and accessible (Rissel et al., 2012).

Mixed-use neighbourhoods have also been consistently associated with additional walking and transit use, and less distance driven. A study of neighbourhoods in eleven nations found that adults reported living near shops, public transit, sidewalks, and bicycle and recreational facilities were 20–50% more likely to meet physical activity guidelines than adults living in neighbourhoods that lacked these features. Those with access to all the amenities were twice as likely to be active as those without access to any (Sallis et al., 2009). Heath & Troped (2012) also found that living near shops, public transit and offices was associated with higher probabilities of walking and using transit, increased socialization, decreased crime and improved services, which all contribute to higher levels of active living and healthy eating.

Torontonians are in favour of having more neighbourhoods designed with the active commuter in mind. In 2013, 81% of

Torontonians surveyed reported believing that more people would cycle if there was more and better cycling infrastructure (e.g. protected bike lanes and paved shoulders) (Share the Road Cycling Coalition, 2013). A survey also found that 75% of Toronto residents expressed a strong preference for a walkable neighbourhood, while only 6% expressed a strong preference for an auto-oriented neighbourhood (Toronto Public Health, 2012b).

Mitigating burden of illness

Neighborhood-scale features that enhance street and sidewalk continuity, improved lighting, improved aesthetics, and traffic calming result in increased physical activity, improved diets and cardiovascular health, greater likelihood of healthy weights, and decreased risk of cardiovascular disease among residents (Heath & Troped, 2012).

Walkable neighbourhoods have been shown to reduce the risk of obesity-related conditions such as diabetes. In Toronto, recent immigrants living in the least walkable neighbourhoods were found to have a 58-67% greater risk of developing diabetes compared to those living in the most walkable neighbourhoods (Mowat et al., 2014). Other studies have also shown that people living in areas of urban sprawl (dispersed low-density single use land patterns) were more likely to be overweight or obese, and suffer from hypertension (Ewing et al., 2014).

Healthy, vibrant neighbourhoods can improve mental health by providing opportunities for social contact and encouraging a sense of social connectedness (Kelly, 2012). Similarly, vibrant public open spaces that encourage people to gather with other people and the natural environment are associated with lower stress, less depression and good health (J. Kent, Thompson, & Jalaludin, 2011). Complete streets have the potential to support social equity, youth and elderly mobility, and improved livability (B. B. Brown et al., 2015; Litman, 2012).

Safety

Dedicated bicycle lanes and paths, sidewalks and traffic roundabouts have been shown to be effective in reducing risk to pedestrians and cyclists, while traffic-calming design features such as street trees, on-street parking and landscaping have been demonstrated to reduce traffic speeds (Retting, Ferguson, & McCartt, 2003). Furthermore, a shift to more active transportation and public transit use could reduce the number of vehicles on the road, and subsequently motor vehicle collisions with other vehicles, pedestrians and other commuters (Mowat et al., 2014).

More detail in provided in the Transportation section of this report.

Access to healthy food

Urban form also influences access to healthy food. Food security (i.e. access to safe, nutritious, affordable and personally acceptable food) is an important determinant of health. Evidence suggests that people are more likely to meet nutritional recommendations when they have ready access to grocery stores with healthy and affordable food, as opposed to convenience stores offering mostly packaged, processed food (Sallis & Glanz, 2009; Smiley et al., 2010). He et al. (2012) found that close proximity to convenience stores and fast food outlets from students' residential or school neighbourhood was linked to less healthy eating habits. Low-income areas also tend to have higher concentrations of fast food outlets (Hemphill et al., 2008), and less access to supermarkets, which generally provide healthier food options (Smoyer-Tomic et al., 2008).

In addition to diversifying land use mixes for better access to different amenities like supermarkets, land use planning can also incorporate various forms of urban agriculture, such as community gardens, which have the potential to help improve the availability of low-cost nutritious food as well as social benefits like a closer sense of community (Armstrong, 2000).

A more detailed discussion of factors that can reduce GHG emissions and potential health benefits can be found in the Food Systems section of this report.

Greenspace

Healthy cities also have urban form that includes abundant, diverse and well-maintained greenspace. Greenspace provides many services, including cooling, carbon sequestration, and direct health benefits. It also provides opportunities for physical activity. A recent review found that urban greenspace of all types and sizes are associated with reduced heat stress, urban heat island (UHI) effect and air pollution (Zupancic, Westmacott, & Bulthuis, 2015). Greenspace is also associated with numerous health benefits, including reduced mortality, obesity, depression, anxiety and cardiovascular disease (Toronto Public Health, 2015b).

Further discussion of the UHI effect can be found in the Buildings section of this report.

Urban form summary and conclusions

Urban form determines how we relate to our city. It significantly influences transportation choices and therefore GHG emissions and health outcomes. Compact, dense, mixed-use neighbourhoods provide the goods and services that people need and the ability to access these goods and services without driving a car. Walkable, transit-oriented neighbourhoods with complete streets and abundant green space increase physical activity as part of daily living. These neighbourhood features provide opportunities to reduce GHG emissions while improving physical and mental health and wellbeing.

Food systems

Global agriculture and food production release more than 25% of all GHGs (Springmann, Godfray, Rayner, & Scarborough, 2016) with increasingly strong impacts on the environment and human health (Friel et al., 2009b; Springmann et al., 2016; Tilman & Clark, 2014). In Ontario, the agriculture system accounts for a significant portion of total GHG emissions: 5.8% of overall GHG emissions, and 37% of the non-CO_2 GHG emissions (Environment Canada, 2015). In turn, climate change is expected to impact many elements of the food system, from production to consumption, including food safety (Tirado, Clarke, Jaykus, McQuatters-Gollop, & Frank, 2010). A recent review by the U.S. Department of Agriculture indicates that climate change will affect physical, social and economic access to food globally and in North America (M. E. Brown, Antle, Backlund, & et al., 2015).

At present, very little of Ontario's food production is within the city itself, and therefore Toronto's GHG inventory does not show emissions related to the food system. Given the importance of the food system to global GHG emissions, and to health, the health benefits of actions to reduce food system GHG emissions are explored here.

Factors that can reduce GHG emissions from food systems

GHG emissions are highly dependent on many factors in the food system, including farming practices. For instance, the type of livestock feed, whether a farm uses petroleum-derived fertilizers and pesticides, and the amount of irrigation would all impact GHG emissions associated with food production. Similarly, whether produce is in-season and grown outside, or out-of-season and grown in a greenhouse, also impacts GHGs. Transportation and packaging also play roles.

Different types of food generate different levels of GHG emissions. More than half of total agriculture emissions in Ontario are attributed to rearing animals (Environment Canada, 2015). While many factors ultimately determine GHG emissions, generally production of plant-based foods has been found to have lower GHG emissions than the production of animal products. Some exceptions are vegetables grown in heated greenhouses or transported by air freight (Carlsson-Kanyama & González, 2009; Smith et al., 2013). Generally, animal-based products tend to have high GHG emissions per unit of energy, serving, and protein compared to plant-based foods (González, Frostell, & Carlsson-Kanyama, 2011).

Table 25 summarizes the GHG emission factors for various food items. Estimates were pooled from 155 lifecycle assessments of GHG emissions (Tilman & Clark, 2014). The table indicates that, of the animal-based foods, beef generally results in particularly high GHG emissions, while poultry, pork, dairy and eggs result in lower emissions.

Table 25 GHG emission factors for various food items

Food item	CO_2-eq emissions (mean and standard deviation (std))			
	g/kcal	g/kcal_std	g/serving	g/serving_std
Sugar	0.07	0.00	3.30	0.01
Roots	0.11	0.07	3.08	0.15
Pulses	0.07	0.01	6.97	0.81
Maize	0.11	0.01	11.00	1.32
Wheat	0.22	0.03	19.07	3.15
Other grains	0.18	0.02	19.80	1.69
Fruits*	0.44	0.11	28.42	6.78
Rice	0.51	0.07	51.33	7.70
Vegetables	2.49	0.92	51.33	12.83
Oils	0.59	0.15	73.33	19.80
Eggs	2.16	0.11	88.00	3.67
Poultry	4.77	0.18	190.67	7.70
Pork	5.87	0.37	223.67	13.20
Dairy	1.91	0.15	271.33	9.17
Beef	20.53	1.50	1210.00	66.00

Notes: Carbon-eq emission factors from Springmann et al. (2016) & Tilman & Clark (2014) were converted to CO_2-eq emission factors by applying a factor of 3.67 (1 ton of C = 3.67 ton of CO2).

*The GHG emission factor for fruit was averaged between temperate and tropical fruits (0.37g/kcal and 0.51g/kcal, respectively).

ADAPTED FROM (Springmann et al., 2016; Tilman & Clark, 2014)

Wealthy populations (relative to the world) like Toronto rely on diets with a higher proportion of animal-sourced foods (Popkin, 2006). Tilman & Clark (2014) reported that mediterranean, pescetarian, and vegetarian diets have the potential to reduce emissions from food production by 30%, 45%, and 55% respectively.

Regarding livestock cultivation, a lifecycle assessment approach could consider the opportunity cost of not having the land available for other uses. If land used for the production of animal products was instead used to sequester carbon over 30-100 years, the resulting carbon sink would hold 25–470% of the GHG emissions associated with the food production (Schmidinger & Stehfest, 2012; Smith et al., 2013).

Many other factors, including where the food is produced and the length of the supply chain, also determine the GHG emissions resulting from food, though the relationships are complex. For instance, a comparison of delivering strawberries from California or Barrie, Ontario to Toronto showed significant emissions savings from the local product. Conversely, local options for meat production or local greenhouse products fared poorly compared to the distantly sourced products (MacRae, Cuddeford, Young, & Matsubuchi-Shaw, 2013).

Generally, shortening the supply chain and producing food locally can have advantages including reducing the need for refrigeration. However, there are exceptions: one study found that, largely due to differences in technology and resources, the waste associated with selected types of Ontario-grown fruit could be greater than that of California-grown fruit (Value Chain Management Centre, 2010). Long distance transport of food is a relatively small contributor to overall energy use in the food system, and typically involves large capacity vehicles (e.g. ship or rail) that are more efficient than smaller trucks that tend to be used for local food delivery (MacRae et al., 2013). However, opportunities exist to create strong city-region food systems that shorten the supply chain, reduce waste and minimize GHG emissions from all stages of the food system.

Wasted food and GHG emissions from it are significant in Toronto and other cities. A discussion of food waste can be found in the Waste Management section of this report.

Sustainable food systems and healthy diets - health benefits

Between 2013-2014, almost half (47.3%) of adults in Toronto reported being overweight or obese while only 39.2% of adults reported eating vegetables or fruits five or more times each day (Public Health Ontario, 2014). Food system and dietary choices can potentially reduce GHG emissions and promote direct and indirect health benefits.

High consumption of red and processed meat, and low consumption of fruits and vegetables, are important risk factors contributing to substantial early mortality (Friel et al., 2009b; Lim et al., 2009; Orlich et al., 2013; Springmann et al., 2016; Tilman & Clark, 2014; WHO, 2004). Consumption of red meat has also been found to increase risk of colorectal cancer (Orlich et al., 2015). Experimental and epidemiological evidence has consistently linked intake of saturated fat with cardiovascular disease (WHO, 2004). Reducing livestock production may also have indirect health benefits related to a lower use of antibiotics (Marshall & Levy, 2011) and subsequent improved water quality (Powlson et al., 2008) and air quality (Moldanová et al., 2011).

Obesity and other diet-related disorders such as diabetes have also been found to affect susceptibility to adverse effects of exposure to air pollutants, such as inflammation and cardiovascular events (J.-C. Chen, Cavallari, Stone, & Christiani, 2007; Zeka, Sullivan, Vokonas, Sparrow, & Schwartz, 2006).

Fish can be a healthy and lower-GHG source of protein and other nutrients. TPH provides a guide to help girls and women select fish that are low in mercury (Toronto Public Health, n.d.).

Local food production, and in Toronto urban agriculture in particular, provides an opportunity for residents to connect with the food system, interact socially and reduce stress (Toronto Food Policy Council, 2012). For people who want to start an urban garden, TPH has a guide to testing the soil quality and reducing any risks (Toronto Public Health, 2013).

Synergy with physical activity

A healthy diet, coupled with sufficient physical activity, is hugely beneficial for health. It reduces the prevalence of a wide variety of health outcomes, including obesity and diabetes. Without healthy dietary habits, exercise has been found unlikely to be effective for achieving significant weight loss (Caudwell, Hopkins, King, Stubbs,

& Blundell, 2009). Physical activity and diet have synergistic effects on health outcomes other than obesity. The coupling of diet and physical activity have been found to be more strongly associated with outcomes, such as reversal of metabolic syndrome, cancer survival, and reduced risk of Alzheimer's disease, than either factor individually (Andersen et al., 2000; Pierce et al., 2007; Scarmeas et al., 2009).

One of the benefits of local food production is that it provides an opportunity for people to be physically active. Gardening, at home or in community gardens, provides an opportunity for people of all ages to enjoy an outdoor, recreational activity (Toronto Food Policy Council, 2012).

Access to healthy food

When people can access affordable, healthy, culturally acceptable food in their neighbourhood by walking or cycling, there is potential for a healthier diet and increased physical actvity. Initiatives to improve the food system and reduce GHG emissions should also consider equity impacts and the potential to improve access to healthy food.

Barriers to healthy eating often include lack of, or limited access to, healthy foods such as fresh fruits and vegetables; and easy access to unhealthy foods such as processed, high-fat, high-sugar and nutritionally-poor foods and beverages (Heath & Troped, 2012). Although a large variety of highly nutritious and diverse food can be found in Toronto, there is an overabundance of less healthy food options. There are, on average, four "less healthy" food stores for every healthier food store within a 1 km walking distance from each city block (Toronto Public Health, 2015f).

Low-income areas tend to be more isolated from healthier food retail outlets. In Toronto, there are almost 31,000 households in low-income areas that are more than 1 km walking distance to a supermarket and over 9,000 of those households live over 1 km away from any kind of food outlet (Toronto Public Health, 2015f). Low-income households have also been found to consume significantly less fresh produce and have a higher prevalence of diet-related chronic disease (Toronto Public Health, 2015f). The Toronto Food Strategy is targeted at addressing this and other barriers to improve nutrition and access to healthy, affordable and culturally appropriate food for all residents (Toronto Public Health, 2015f).

Food systems summary and conclusions

GHG emissions related to food systems are significant at the global, national and provincial level. The majority of the food consumed in Toronto is produced outside of the city, and therefore the GHG emissions resulting from food production are not captured in Toronto's inventory.

Many factors affect the GHG emissions from the food system. Strategies that can potentially reduce food system emissions include increasing sustainable production, improving local availability of healthy food, shifting diets to more plant based foods, and reducing food waste.

This report provides an introduction to the health benefits associated with reducing GHG emissions from the food system. TPH is currently undertaking further work as part of the Climate Change and Health Strategy for Toronto. TPH is investigating opportunities to support sustainable food systems that increase access to healthy food and increase local food production. TPH is also assessing the impact that climate change will have on food safety, security and sustainability, including reducing GHG emissions (Toronto Public Health, 2015a).

Waste management

Emissions from the Ontario waste sector are primarily from landfill gas, which contributes about 5% of the province's total emissions (Ontario Waste Management Association, 2015). A major component of reducing emissions from the waste sector involves reducing the quantity of organics going to landfill, in order to reduce emissions from landfills.

Taking a broader perspective, by minimizing waste production, it is possible to reduce emissions of GHGs and other pollutants from waste management, as well as to reduce upstream emissions resulting from production and distribution of materials that are later disposed.

When considering the waste management sector, much of the emissions attributable to waste generated in Toronto occur outside of Toronto's boundaries. However, because of the importance of waste management in reducing a city's GHG emissions, actions to reduce GHG emissions from waste, and potential health benefits of those actions, are considered here.

Waste prevention

Preventing waste from being generated in the first place is the most effective way to minimize GHG emissions, and potential health impacts from waste. Preventing waste benefits health by eliminating potential impacts to air, soil and water from waste transportation, processing and disposal. It also decreases upstream impacts from mining and refining of virgin materials, manufacturing processes, and distribution of materials that are later disposed.

For instance, Cleary (2014) identified and estimated the impacts in Toronto of five waste prevention activities – those focused on admail, disposable bags, newspapers, wine and spirits packaging, and grass cycling. Cleary estimated these activities would result in an estimated 13% reduction in disability-adjusted life year (DALY), or 65 DALYs relative to 2008. In the example of admail, (Cleary, 2014) estimated that 4.7 kg/capita of unwanted admail could be prevented in Toronto annually. The upstream emission reductions were estimated to result in 23.2 fewer DALYs compared to 2008. The Cleary analysis is of particular interest because it is specifically for Toronto, and we were unable to identify other analyses that looked at the health benefits of waste reduction.

Another example of a targeted waste-prevention campaign focused on plastic shopping bags. Disposable plastic bags were targeted for waste prevention through the Ontario Plastic Bag Reduction Initiative, which reduced plastic bag distribution in Ontario by 58% within 3 years of being introduced in 2006; a reduction of approximately 2.5 billion bags (Ontario Plastic Bag Reduction Task Group, 2010). In 2008, it was reported that approximately three billion disposable plastic bags were distributed in Ontario in 2008 (Ontario Plastic Bag Reduction Task Group, 2010). Cleary's (2014) assessment for Toronto estimated that the disposable bag prevention activity results in 3.24 fewer DALYs compared to 2008 from upstream emission reductions. Toronto has benefited from past policies to charge fees for plastic bags. Even with the repeal of the bylaw some retailers have continued to charge a fee, incenting the continued use of reusable bags.

Waste prevention activities, as evidenced by these few examples, can reduce emissions as well as health impacts, through the lifecycle of the article being disposed: production, distribution, use, and processing or disposal.

Reducing food waste

Forty percent of all the food Canada produces, valued at estimated CAD$31 billion ends up in the landfill and compost each year, creating unnecessarily high levels of carbon and methane (Gooch & Felfel, 2014).

It is estimated that 50-67% of unnecessary food waste occurs in the home (Value Chain Management Centre, 2010; von Massow, 2015). Consumers tend to purchase more food than they need, resulting in edible food being wasted and disposed. More than 60% of the avoidable waste consists of fruits and vegetables, suggesting that a significant amount of the healthiest foods is being thrown out (von Massow, 2015). Although fruits and vegetables are more prone to spoiling than most foods, proper planning before buying can reduce wasted food. Preventing food waste through donation can also make healthy food options available to communities with lesser access, such as low-income families living in food deserts. The health benefits of a healthy diet have been discussed in the *Food systems* section.

Toronto's Long Term Waste Management Strategy

Toronto is developing a Long Term Waste Management Strategy (Waste Strategy) that prioritizes reduction, reuse, recycling, and recovery of any remaining resources, to minimize the amount of waste requiring disposal. In other words, the Waste Strategy considers both the upstream and downstream impacts from waste generation and management.

Toronto Public Health conducted a rapid Heath Impact Assessment of the options in the Waste Strategy, and determined that the options with the greatest potential for health and equity benefits are those that focus on waste reduction and reuse. These options include a food waste reduction strategy, sharing libraries, and a textile collection and reuse strategy (Toronto Public Health, 2016). One key advantage of the waste reduction and reuse options is the focus on prevention, minimization and reuse of waste, which are preferable to resource recovery and disposal options that require financial support, dedicated energy input and a greater associated potential for adverse health impacts. This is consistent with the preferred waste management hierarchy. A summary of the health impact assessment and potential to increase health care costs is shown in Table 26.

Regarding food waste, the City of Toronto updated its waste audit sort categories to delineate between wasted food (i.e. edible foods) and food waste (i.e. inedible food such as bones and peelings). This additional breakdown allows better tracking and measuring of quantities of food in different waste streams (e.g. garbage, Blue Bin recycling, Green Bin organics) (City of Toronto, Solid Waste Management Services, 2016).

Toronto's Waste Strategy recommends implementing a food waste reduction strategy that focuses on information and outreach programs to educate residents about the benefits of food waste reduction from an economic, environmental and social perspective. If successful, this option could help reduce the need for new Green Bin organics processing infrastructure, and would lower the amount of both Green Bin organics and garbage to be managed (City of Toronto, Solid Waste Management Services, 2016), as well as reducing upstream emissions of GHGs (and other substances) related to food production and distribution.

Table 26 Health impact score, and potential to increase health care costs, for options under consideration for Toronto's Long Term Waste Management Strategy (Toronto Public Health, 2016).

Waste management option	Health Impact Score*	Potential to Increase Health Care Costs
Waste Reduction and Reuse		
Food Waste Reduction Strategy	10	Low
Explore Opportunities for Waste Exchange	5	Low
Textile Collection and Reuse Strategy	5	Low
Sharing Library	5	Low
Support Reuse Events	2	Low
Multi-Residential		
Alternative Collection Methods for Multi-Residential Buildings – Vacuum system	8	Low
Alternative Collection Methods for Multi-Residential Buildings - One container system	7	Low
Community/Mid-Scale Composting	5	Low
On-site Organics Processing	3	Low
In-Sink Disposal Units	3	Low
Updates to Current Multi-Residential Development Standards	1	Low
Mandatory Multi-Residential By-law	1	Low
Container management	1	Low
Multi-Residential Collection using Alternative Vehicles	1	Low
Elimination of Collection Service to Multi-Residential Buildings	-9	Medium
Drop-Off Facilities		
Develop a Network of Permanent, Small Scale Neighbourhood Diversion Stations in Convenient Locations	4	Low
Develop a Mobile Drop-off Service for Targeted Divertible Materials	2	Low
Stand Alone Drop-off and Reuse Centres	0	Low
Incentive Based Mechanisms		
Incentive based drop off system (e.g. reverse vending machines)	2	Low
Deposit-return System for City of Toronto for Selected Materials	2	Low

Waste management option	Health Impact Score*	Potential to Increase Health Care Costs
Construction, Renovation and Demolition		
Depots, Processing, and Policies to Divert Construction, Renovation and Demolition (CRD) Waste	2	Low
CRD material disposal bans	1	Low
Industrial, Commercial and Institutional (IC&I)		
Expand City of Toronto Share of IC&I Waste Management Market	1	Low
City Implements IC&I Waste Diversion Policies	1	Low
City of Toronto Exits the IC&I Waste Management Service	-5	Medium
Control, Influence & Enforcement		
City Explores Mechanisms to Introduce Additional Controls Over Waste Management – Bans, By-laws and Acts	1	Low
Commissioners - Transfer Stations		
Procure Transfer Capacity at a Private Transfer Station in Vicinity of the Port Lands Area (if available)	-5	Medium
Relocation of Transfer Station within the Port Lands Area or Designation of Land for Long-Term Relocation	-6	Medium
Redirecting Waste to an Existing Transfer Station(s)	-6	Medium
Recovery – New Facilities		
Organics Recycling Biocell or Biomodule Facility Development	1	Low
Mixed Waste Processing with Organics Recovery Facility Development	-3	Medium
Mixed Waste Processing Facility Development	-5	Medium
Waste to Liquid Fuel Technologies Facility Development	-13	Medium
Emerging Technologies Facility Development	-14	Medium
Direct Combustion Facility Development	-15	Medium
Residual Waste		
Adjust Tipping Fees or Customer Base	2	Low
Bio-reactor Landfill	-2	Medium
Purchase a new (existing) landfill	-17	Medium
Residual to 3rd Party Disposal Facility to Preserve Landfill Capacity	-17	Medium
Residual to 3rd Party Disposal Facility as Long Term Waste Management Option	-17	Medium
Landfill Expansion	-18	Medium
Greenfield Landfill	-19	Medium

*Notes: Health impact scores were evaluated through multiple determinants of health lenses: environmental, socioeconomic, lifestyle, service accessibility, and equity. Their potential for health impacts was categorized as positive (score greater than five); neutral (score between 0 and 4); and, adverse (negative scores).

Residual waste

Even with a successful Waste Strategy, the City will still need to address the residual waste that remains after reducing, reusing, recycling and recovering remaining resources. The primary means of disposing of Toronto's residual solid waste is landfill.

Epidemiological studies of the health impacts associated with residual waste-management options including landfill are available, though the studies note limitations (Porta, Milani, Lazzarino, Perucci, & Forastiere, 2009). The rapid Health Impact Assessment indicated that the residual waste management options in Toronto's Waste Strategy have the greatest potential adverse impacts on public health of the options considered. These options also have the greatest potential environmental, social and financial impacts (Toronto Public Health, 2016).

Recycling, composting and anaerobic digestion generally contribute fewer GHG emissions relative to landfilling (Table 27). The values in this table include the "carbon storage effect" which measures the quantity of carbon implicitly captured in the object in its production.

Table 27 GHG emissions from waste management options compared to landfilling (option's net emissions minus landfilling net emissions), including carbon storage effects (tonnes CO_2e/t)

Material	Recycling	Composting	Anaerobic Digestion	Combustion
Newsprint	-1.53	NA	0.72	1.16
Fine Paper	-4.38	NA	-1.52	-1.22
Cardboard	-3.54	NA	-0.6	-0.33
Other Paper	-3.98	NA	-0.95	-0.75
Aluminum	-6.51	NA	0	0
Steel	-1.2	NA	0	-1.04
Copper Wire	-4.11	NA	0	0
Glass	-0.12	NA	0	0
HDPE	-2.29	NA	0	2.87
PET	-3.64	NA	0	2.15
Other Plastic	-1.82	NA	0	2.65
Food Scraps	NA	-1.04	-0.9	-0.78
Yard Trimmings	NA	0.09	0.18	0.34
White Goods	-1.48	NA	0	-0.27
Personal Computers	-1.61	NA	0	0.4
Televisions	-0.24	NA	0	0.73
Microwaves	-1.28	NA	0	-0.56
VCRs	-0.97	NA	0	0.14
Tires	-3.31	0	0	-0.5

SOURCE: (ICF Consulting, 2005)

The City of Toronto owns one active landfill: the Green Lane Landfill in Southwold, Ontario. This is where City managed waste is being disposed. The City is also responsible for the perpetual care and maintenance of 160 closed landfill sites that emit methane (CH_4 – a greenhouse gas).

The City has estimated 2013 GHG emissions from City-owned and maintained landfills at 750,946 t (City of Toronto, 2015). The City's GHG reporting protocol focuses on disposal related GHG emissions, and does not currently account for waste diversion initiatives that help to reduce GHG emissions through waste reduction, recycling and composting. The quantities reported to Environment Canada for 2013 for landfill sites above the 25 kt/a reporting threshold are shown on Table 28.

Table 28 Greenhouse gas emissions (tonnes) from City of Toronto waste management sites reported to Environment Canada for 2013

GHG gas	Green Lane LF	Keele Valley LF	Brock West LF	Total
CO_2	117.87	7,058.24		7,176.11
CH_4	3,099.84	18,827.81	1,469.30	23,396.95
N_2O	0.01			0.01
Total (CO_2e)	**77,616.00**	**477,753.00**	**36,732.00**	**592,101.00**

Emissions of other reportable compounds from these sites in 2013 are shown in Table 29. Landfill gas is created when buried waste decomposes. This gas is roughly 50 per cent methane and 50 per cent carbon dioxide, along with traces of other gases (Solid Waste Management Services, City of Toronto, n.d.). GHG emissions from landfills are reduced by flaring, which converts the methane into carbon dioxide. Alternatively, the methane may be recovered and used to generate renewable electricity, or be used as renewable natural gas which can be injected directly into the local gas-distribution network.

Table 29 Emissions from the Green Lane landfill, Keele Valley landfill and landfill power plant, as reported to Environment Canada's National Pollutant Release Inventory (tonnes)

	Green Lane Landfill	Keele Valley Landfill	Keele Valley Landfill Power
Pollutants	**2013**	**2014**	**2014**
CO	159.00	0.02	22.00
PM - TPM	21.00	94.00	1.90
PM10	8.40	43.00	1.60
PM2.5	4.10	15.00	1.60
VOC	20.00	0.03	3.70
SO2	-	0.03	7.90
NO_2	-	0.02	225.00

Currently the gas at the Green Lane landfill is collected and directed to a flaring system that converts the methane into carbon dioxide. The potential for a future biogas utilization facility is currently under review by City of Toronto Solid Waste Management Services.

Waste management summary and conclusions

Toronto's GHG inventory captures emissions associated with landfills owned by the City, even though they are outside the city's boundaries. Actions to reduce these emissions relate primarily to the management of landfill gas, of which methane is the principal component. Over time, the generation of landfill gas will be reduced if less waste is landfilled.

More broadly, reducing the production and use of materials, through reducing, reusing, recycling and recovery, can also result in upstream GHG reductions. Data on the health benefits or harms associated with emission-reduction actions in the waste sector are limited in the scientific literature.

Limitations and gaps

The two starting points for this work were the global overviews of GHG reductions and health from the scientific literature, and the City's GHG emission inventory for Toronto in 2013. The global overviews place a large emphasis on the phasing out of coal as a way to achieve significant health benefits through reduced air pollution. This has already been achieved in Ontario, and is responsible for a significant part of the reduction in emissions that Toronto has seen between 1990 and 2013, the most recent year for which GHG emissions in the city have been estimated.

Limitations

Limitations of Toronto's GHG inventory for use in assessing health impacts

Toronto's GHG emission inventory points to the progress that has already been made, the challenge remaining to get to the 2050 target, and sectors where there are the greatest reduction potentials. The inventory shows that roughly 40% of the GHG emitted is from natural gas combustion and 10% from electricity generation (primarily used for buildings); 40% is for transportation; and 10% is related to emissions from City-owned landfills.

Although not included in the most recent inventory, previous years' inventories also reported emissions of nitrogen oxides related to the sources of GHG emissions, as a surrogate for air quality. Based on this surrogate, those inventories indicated that transportation was responsible for about 80% of the air pollution created in the city, and buildings and point sources for the other 20%. (Most electricity generation and all landfills are outside the city boundaries; about half the air pollution in the city is from outside the city). Although not a source or sector itself, urban form is a major driver of both building and transportation emissions.

The inventory has limitations in supporting efforts to reduce GHG emissions and to promote human health. First, the transportation emissions have not been updated since 2008. Given that transportation is the largest single source category for GHG emissions and dominates air pollution emissions, this is troubling, although the City recognizes the issue and is planning to update and improve the transportation estimates. A more recent and rigorous estimate of transportation emissions for the Toronto Metropolitan Area that includes neighbouring municipalities reports GHG emission only about 50% higher than the Toronto only study (McMaster Institute for Transportation and Logistics, 2014). Although the McMaster study does not break out Toronto from the Toronto Metropolitan Area, given that the Toronto Metropolitan Area has about double the population of Toronto, and is generally less dense and more auto dependent, Toronto's transportation emissions may be lower than reported in the inventory. More troubling, though, is that the McMaster study includes projections of emissions in 2016 that suggest transportation related emissions are rising.

The second limitation of Toronto's inventory is one that is designed in. Consistent with best practices, the inventory is (primarily) a 'scope 2' inventory, meaning that it addresses only sources of emissions within the city boundaries, and GHG emissions related to electricity generated for use in the city. It does not consider emissions that occur outside the city to produce the food and goods that are consumed within the city. Yet some of these actions – like changing diet to consume less red meat – have potentially large GHG-reduction and health benefit potential.

Finally, GHG impacts are largely global, whereas health impacts from air pollution, and noise, for example, are highly local. Thus to fully assess those impacts requires detailed spatial resolution on sources of emission, and the population exposed to those emissions.

Limitations of the literature on health effects of actions and measures to reduce GHG emissions

There are challenges in comparing health impacts across studies, geography and sources, and extending those to populations. Across studies, different studies use different metrics for measuring impacts, and different methods for valuing those metrics. The most universal metric is dollars, though different studies include different economic components, or different assumptions, e.g. the value of a human life. In many cases, the base metrics are not clearly reported. Across geography, local circumstances vary widely, and many assessments are sensitive to these variations. For example, the electricity mix is different in each jurisdiction, as are such things as the distribution and demographics of the population, urban form and local climate. These variations complicate applying results from other jurisdictions to Toronto with confidence, and thus many analyses from other jurisdictions are indicators of possible opportunities that will need to be assessed for specific benefits or harms that may result in Toronto.

The literature does not typically compare health impacts of various actions or measures across sectors. Within sectors, active transportation may be compared to other transportation modes, for example, but it is uncommon to compare changes in transportation mode with retrofitting buildings, for example.

Many of the health assessments have been done with a focus on individual projects, such as individual buildings or specific roadways, and it is not clear when these may be generalized to all buildings or all roadways.

Limitations arising from a focus on actions not measures, and mitigation

In this report, we have focused on the *actions* that result in reductions in GHG emissions, and the health impacts associated with those actions. We have largely ignored the *measures*, i.e.

policy initiatives, financial incentives or disincentives, or information or moral suasion campaigns, that might encourage these actions to be adopted. Those measures will be important considerations in realizing these actions.

The project is focused on the GHG-reduction initiatives, and does not attempt to consider health impacts associated with climate change itself, or adaptation measures.

Planning in the face of these limitations

Planning necessitates making decisions in spite of data limitations, hopefully with recognition of those limitations. There is sufficient evidence from other jurisdictions to indicate that there are opportunities to realize health benefits while reducing releases of GHGs.

It is possible for the City to address at least some of the identified limitations by:

- Continually refining the GHG inventory for the City, including by reporting items more clearly by scope, restoring estimation of air quality indicators, and clear documentation of methods and sources. To support health analyses, greater resolution would be desirable, including greater detail on building and vehicle types and vintages, and geographic distribution, for example.
- This project was commissioned to review what the literature was saying about the health implications of GHG-reduction initiatives. To better understand the relevance and applicability of the findings from other jurisdictions or specific project assessments would require modelling of major measures, taking into account Toronto's specific circumstances.
- Assessing and monitoring the health impacts of GHG-reduction measures as they are introduced. This would serve both to understand better what these are, and to

ensure that the specific method of implementation supports health protection goals as well as climate protection goals. For greatest usefulness, these assessments should clearly document major assumptions, sources, and conclusions.

- Although not specifically health related, research and modelling will be required on potential measures to encourage adoption of the actions reviewed. These include regulatory, financial or information measures.

Conclusions

Actions to reduce GHG emissions have the potential to enhance human health, and overall are likely to do so. The review of the literature points to several health considerations related to GHG mitigation actions that should be addressed during the review and evaluation of those actions:

- Does the mitigation action have the potential to result in increased levels of physical activity, which has significant health benefits?
- Does the mitigation action result in a reduction in the release of, or exposure to, air pollution?
- Does the mitigation action encourage the adoption of a healthier diet?
- Does the mitigation action lead to a reduced risk of accident or injury?
- Does the mitigation action reduce the level of noise to which the public is exposed?

In general, assessments of mitigation actions that have been proposed or implemented already point to a positive relationship between GHG-reduction actions and health benefits. In general, where there are harms, those harms can be addressed through proper design and implementation of the GHG mitigation strategy.

The largest quantities of scope 1 GHG emissions are from transportation and buildings, which pose different opportunities and challenges.

Opportunities in the transportation sector

Transportation, in addition to releasing GHGs, is a major source of air pollution, noise, and injury and deaths from collisions. The total amount of emissions from transportation depends on the number and types of vehicles on the road, and how heavily they are used.

New regulations for vehicles can be expected to reduce both GHGs and air pollution from vehicles very substantially by 2050 as the vehicle stock turns over. Greater adoption of battery-electric vehicles in place of conventional vehicles will also reduce vehicle emissions. Health impacts associated with the transportation sector that will be reduced with lower levels of air pollution include: reduced ischemic heart disease and reduced acute respiratory diseases.

These impacts from transportation can also be offset by increased adoption of active transportation, which brings significant additional health benefits associated with higher levels of physical activity. Among the health benefits of increased physical activity are reduction in obesity and type 2 diabetes, reduced depression, and reduced breast and colon cancers.

Within the transportation sector, heavy vehicles are responsible for a greater share of air pollutants than they are of GHG emissions. A priority will be getting older vehicles off the road, as these are the heaviest polluters.

In the transportation sector, as well as other sectors, careful design will be required to avoid creating additional health risk. An example of such a design feature is establishing safe active-transportation infrastructure to ensure that residents who switch from driving to active transportation are able to walk or cycle without increased exposure to risk of accident or injury. Another example is ensuring that there are appropriate systems for the safe handling and recycling of batteries used in electric vehicles.

Opportunities in the building sector

In some ways, substantially reducing GHG emissions from buildings will be a bigger challenge because building stock turns over more slowly, and deep retrofits of existing buildings are costly and intrusive. Existing buildings of many types need to be retrofitted to reduce GHG emissions. In making those deep retrofits, care must be taken to fully consider the health of occupants. Direct measurements of indoor air quality need to be supplemented with health surveys or tests of occupants, as changes in health are not necessarily evident from air quality measures alone.

Opportunities to enhance health benefits appear to be particularly significant in older housing where residents have modest incomes. These buildings are more likely to have poor ventilation or indoor air quality, and residents often have little or no control over temperature. Retrofitting these buildings in particular will enhance multiple aspects of human health. Some of the health benefits reported include: reduced sinusitis, hypertension, obesity, and asthma attacks, as well as increases in overall health scores that take into account cardiac, respiratory and mental health.

There is an opportunity to further reduce GHG and emissions from natural gas combustion by switching to other types of energy, including electricity or renewables.

In all sectors, including the building sector, even within specific action types, there are sometimes significant variations in the health impact. For example, studies looking at health benefits of building retrofits generally find positive health outcomes, but some residents also report having negative impacts. This points to the need to plan and implement measures carefully, consider health, and monitor results.

Opportunities through changes to urban form

Addressing urban form can support reductions from transportation and buildings, and achieve associated health benefits, by facilitating active and public transportation and denser development. Appropriately implemented, urban form can help enable numerous other opportunities, including:

- Reduced reliance on automobiles, and attendant benefits of reduced air pollution, noise, injuries and deaths;

- Increased opportunity for active transportation through reduced travel distance, and enhanced safety and desirability of active transportation, e.g. through separation from vehicles;
- Increased building density, typically meaning buildings that use less energy and produce fewer GHGs;
- Increased availability and access to healthy food in so called "food deserts" by ensuring mixed-use development; and
- Improved access to abundant, diverse greenspace.

Opportunities related to scope 2 and scope 3 emissions

Toronto's emissions related to electricity generation and waste management outside the city boundaries are a relatively minor source of GHG emissions, and are largely being controlled already. Electricity generation in Ontario is mostly carbon-free, with the 10% that is fossil derived coming from natural gas, the cleanest fossil fuel.

Reducing other scope 3 emission sources, other than waste management facilities, has the potential to have significant benefits to human health. In particular, motivating consumers to shift to a more sustainable and healthier diet can reduce GHG emissions and benefit health. For instance a healthy diet based less on meat and more on plants could result in noticeable reductions in certain cancers, cardiovascular disease, and obesity-related diseases. More generally, GHG reductions and health benefits can result from improving the sustainability of the food system at all stages, and ensuring that fresh, affordable food is available locally. Other scope 3 emissions, such as those embodied in products used in Toronto, could be examined for GHG-reduction opportunities.

Priority initiatives

Based on the literature, the following actions and measures offer significant opportunities for concurrent GHG reductions and health benefits:

1. Enabling active transportation to reduce automobile use and encourage increased physical activity;
2. Retrofitting older, low-income housing, to reduce energy consumption and enable healthy indoor air, temperatures that are safe and comfortable, and improved quality of life;
3. Encouraging faster turnover of older vehicles, and especially of heavy trucks, as those vehicles are the most polluting;
4. Focusing on urban form that promotes increased density, mixed-use development, and non-vehicle transportation, enhancing opportunities for safe active transportation, reducing the demand for energy for transportation and buildings, and making goods and services more readily available; and
5. Making changes to the food system to emphasize sustainable, healthy, affordable and locally available foods, to reduce GHG emissions and lower the prevalence of diet-related diseases.

Tactical and strategic considerations

Health impacts have important distributional variations: health impacts vary with distance from major roads, low-income residents may benefit more from building-efficiency upgrades, and conclusions about life-cycle risks and benefits of new technologies are sensitive to assumptions about things like the fuel used to generate electricity. These distributional variations point to the need for interventions to be tactical.

At a strategic level there are competing perspectives. To meet the GHG reduction targets for 2050, it is important to focus on strategies with long gestation periods or persistence: urban form, changing habits (e.g. around physical activity and diet), and buildings, which turn over slowly. The older, heavy vehicles on the road today, which are a major source of air pollutants, will almost all be gone by 2050, replaced by newer, much cleaner vehicles designed to meet standards that would have already been enacted. But this longer-term focus needs not foreclose taking advantage of short-term opportunities, such as instituting low emission zones that limit access of those most polluting vehicles to areas with dense populations.

Steps for the City to take

To increase confidence in the conclusions and relative importance of various actions across sectors, the City needs to address the limitations and gaps identified through both modelling of impacts of initiatives that are proposed, and through assessment and monitoring of those initiatives as they are implemented.

The City can also continue to show leadership to the community by ensuring that its own facilities and activities promote lower carbon emissions and healthy alternatives, whether through the renewable energy policy for city facilities, retrofitting its own facilities, or greening the City fleet.

Measures identified in the literature for reducing GHGs and promoting public health are largely the ones that the City is already pursuing through such initiatives as Active City, the Toronto Food Strategy, the Toronto Green Standard, Tower Renewal, work on complete streets, and other programs. Continuing and extending these initiatives will enhance health benefits and support reductions in GHGs.

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Appendix A. Survey of methods for quantifying health benefits and impacts

The valuation of health effects is important in comparing and prioritizing measures with similar qualitative health impacts. The health assessment tools selected to evaluate the health impacts resulting from mitigation actions will largely depend on the health driver or pathway through which health impacts are achieved. In this report, the following heath pathways are identified:

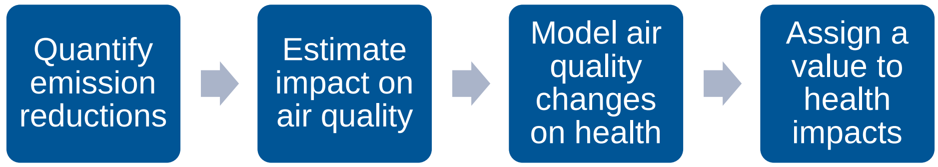
- Air quality;
- Physical activity;
- Diet;
- Traffic accidents; and
- Noise.

Models specific to quantifying the health impacts as a result of diet changes and noise pollution were not found but can be evaluated using the health impact function and IOMLIFET, both described below. Health assessment tools specific to air quality changes, physical activity changes, and traffic accidents are detailed below.

Air quality

Improved air quality has been found to reduce premature deaths due to trachea, bronchus and lung cancers, hypertensive heart disease, ischemic heart diseases, chronic obstructive pulmonary disease, asthma and other respiratory diseases (Jensen et al., 2013).

The methodology for quantifying health impacts can be broken down into four main steps, though depending on the purpose of the analysis, some of these may not be necessary:



1. **Quantify air and GHG emissions reductions from the mitigation actions**. For stationary fuel combustion (e.g. natural gas), there are published emission factors that relate to the quantity of fuel consumed (or saved). For example, Canada's National Inventory Report documents current emission factors used to determine emissions in Canada. For transportation related emissions, releases are often measured in vehicle-kilometres travelled rather than fuel use. Emissions also vary significantly by vehicle type and vintage. The typical output of this step will be emissions, by type, per unit of time (e.g. kilograms per year).
2. **Estimate the changes in air quality resulting from these emissions reductions**. These methods translate emissions (mass/time) to pollutant concentration changes (mass/volume) in the area of interest. The assessment of health impacts as a result of air quality is challenging as it is impacted by the spatial distribution of the releases, their fate and transport in the environment, and the characteristics of the exposed population. Air quality modeling will typically output changes in air quality (e.g. in micrograms per cubic metre).
3. **Estimating the health impacts of these air quality changes**. Input requirements will typically be pre-existing incidence of the health end-point, and population exposed to changed concentrations by the level of the change, and by population characteristic (e.g. age, sex, health status). The output of this step will typically be the number of cases of a particular health endpoint (e.g. all-cause mortality, hospital admissions).
4. **Assign a value to the health impacts**. Health impacts are typically converted into dollar terms for benefit-cost analyses. Various ways of assigning the value have been developed, based on the willingness to

pay and health care costs. The typical output of this step will be cost over time, e.g. dollars per year.

Benefit-per-tonne estimates

The benefit-per-tonne (BPT) approach estimates the average monetized benefit of unit changes in pollutant levels (Fann, Fulcher, & Hubbell, 2009). These values are based on broad level analyses (i.e. Canadian or Ontario-wide plan) and are adjusted to approximate the effects of smaller-scale efforts in the same region, reflecting differences in localized factors affecting individual regions. These values represent a composite of the air quality modeling, health impacts estimation, and valuation estimation steps used in more complex models.

The United States Environmental Protection Agency developed $PM_{2.5}$ BPT estimates that are categorized by key precursors, source category, and location of the county (Fann, Fulcher, & Hubbell, 2009). These estimates enable quick and simple analyses by multiplying the emission reduction by the relevant BPT metric.

The Climate Protection Partnerships Division in EPA's Office of Atmospheric Programs summarizes the advantages and disadvantages of using BPT estimates below (United States Environmental Protection Agency, 2011) in Table A 1.

Table A 1 Advantages and disadvantages of the BTP approach (United States Environmental Protection Agency, 2011)

Advantages	Disadvantages
Simple: only requires forecasted or historical level of emission reductions	**Based on multiple assumptions:** assumptions are specified within a specified spatial scale, and cannot be modified including C-R functions, year of population exposure, air quality modeling
Quick results: estimates can be obtained very quickly	**Assumed linear trend:** Actual health impacts are not believed to be linear

These advantages and disadvantages are generally shared among basic modelling approaches (e.g. the more simple and quickly results can be generated, the less the model captures real world complexity).

Illness Cost of Air Pollution (ICAP) model

The Ontario Medical Association developed the ICAP tool to estimate health outcomes and health care costs associated with four major health endpoints: premature mortality, hospital admissions, emergency room visits, and minor illnesses (Ontario Medical Association, 2005). Each of these health endpoints may be further broken down to more specific illness categories, age groups, and geographic locations.

Default values in the ICAP model include the Value of Statistical Life (VSL) which is based on values derived in a Canadian study (Krupnick et al., 2002), Canadian census data, air quality estimates provided by the Ontario Ministry of the Environment, and base incidence rates and concentration-response functions based on various sources (Ontario Medical Association, 2005).

Air Quality Benefits Assessment Tool (AQBAT)

Health Canada developed AQBAT to estimate the health impacts associated with changes in ambient air quality through MC simulations to provide a range of likely health effects outcomes and associated economic valuations for each scenario.

The fundamental assumption within AQBAT assumes a linear relationship between health endpoint cases attributable to changes in pollutant concentration and the relative risk value, concentration change, baseline health endpoint rate, and population. Major health endpoints evaluated include chronic exposure mortality, cardiac hospital admissions (elderly and adult), respiratory hospital admissions, cardiac ER visits, respiratory ER visits, bronchitis (adult, child acute), asthma symptom days, acute respiratory symptom days, and restricted activity days (SENES Consultants Limited, 2013).

Reported limitations are that baselines prior to 2003 cannot be used, and missing relative risk values for certain health endpoints (e.g. respiratory and cardiovascular hospital admissions) (SENES Consultants Limited, 2013).

Physical activity

The Canadian Physical Activity Guidelines recommend that all adults aged 18 and over obtain 150 minutes of physical activity each week, in sessions of at least 10 minutes. This corresponds to 30 minutes of physical activity (a 2 km walking trip or a 7.5 km biking trip), 5 days per week (Toronto Public Health, 2012a). There is strong evidence that physical activity reduces the risk of diabetes, cardiovascular disease, breast cancer, colon cancer, and dementia (Woodcock et al., 2009).

Health Economic Assessment Tool

A popular method to evaluate health benefits for active transport scenarios is WHO's health economic assessment tool (HEAT). The

World Health Organization developed and released the HEAT model to project population mortality rate improvements that result from active transportation. More specifically, the model projects the economic value of mortality rate improvements if x number of people walk or cycle y distance on most days (WHO). The model parameters can be changed to adapt to the situation and context in question.

Various uses of the model outputs include:

- Cost-benefit analysis of transportation or infrastructure interventions;
- Economic quantification of transport interventions on climate emissions;
- Assessment of present situation and/or comparison with past;

Health impact functions can also be used to quantify health impacts as a result of physical activity. However, sensitivity analyses consistently show that different modeling techniques of the health impact of physical activity produce very different results and highlight the need for a consensus on the most reliable approach.

Traffic-related injuries

Pedestrians and cyclists face a greater risk of injury or death from traffic collisions than motor vehicle users (Elvik, 2009) and cycling is perceived as being less safe than driving (Doorley, Pakrashi, & Ghosh, 2015).

Meta-analyses of crash data also show that as more people that walk and cycle, the safer it becomes to walk and cycle per person (Jacobsen, 2003). Jacobsen (2003) found that the doubling of people walking would lead to a 32% increase in total injuries which equated to a 34% reduction in each walker’s individual risk.

A common foundation of traffic-related accident models evaluates I, number of cases of mortality or morbidity, follows the form $I=aE^b$, where E is a measure of amount of walking or cycling, and a and b are empirical parameters. Studies find that b is consistently below 1 (generally between 0.1 and 0.7), indicating that risk of injury or crash declines with increased active travel (de Nazelle et al., 2011).

General health assessment tools

Health impact function

The assessment through a health impact function is one approach to quantify health impacts from climate change mitigation actions. More specifically, health impact functions quantify changes in specified health endpoints as a response to changes in pollutant concentration, and is frequently termed as a 'concentration-response (CR) function' or 'exposure-outcome' functions. This method is particularly flexible and can account for varying levels of severity though choice in health endpoint (e.g. mortality vs. morbidity) and different types of risk exposure (e.g. pollutant concentrations, physical activity, diet changes). Health impact functions take the basic form below:

$$\Delta Health\ endpoint = -\left[y_0 \cdot \left(e^{-\beta \cdot \Delta C} - 1\right)\right] \cdot pop$$

where:

y_0 = baseline incidence rate for health endpoint

β = relative risk (RR) factor

ΔC = change in exposure level/concentration

pop = population

σ_β = standard error of β

The function combines pollutant level changes, the affected population, and information regarding the expected incidence change per person as a result of a change in exposure level (EPA, 1999). The expected incidence change in this case is defined as the excess risk per unit increase in exposure, and is frequently termed as 'relative risk' (RR). These values are derived from extensive epidemiological studies and it is important to select studies that are most similar to the affected population in the City of Toronto in order to accurately evaluate health impacts linked to changing pollutant levels.

Table A 2 summarizes some example CR functions evaluating different health effects associated with reduced exposure to ozone. However, recent epidemiological studies for populations similar to the one of interest may be unavailable and it may be difficult to select an appropriate RR value for particulate matter due to the overabundance of available RR values in the body of literature.

Hoek et al. (2013) summarized the evidence from epidemiological studies on long-term exposure to PM, NO_2, and elemental carbon on mortality from all-cause, cardiovascular disease, and respiratory disease. The pooled estimates expressed as excess risk per 10μg/m^3 increase in $PM_{2.5}$ exposure were found to be 6% for all-cause mortality,11% for cardiovascular disease, and 3% for non-malignant respiratory disease. Pooled estimates for all-cause mortality by elemental carbon was found to be 6% per 1μg/m^3 increase and 5% by NO_2 per 10μg/m^3 increase.

Table A 2 Example concentration-response functions

Health endpoint	CR function	Source of CR function
Hospital admissions – all respiratory	$\Delta All\ respiratory = -[y_0 \cdot (e^{-\beta \cdot \Delta O_3} - 1)] \cdot pop$ where: y_0 = daily hospital admission rate for all respiratory per person = 2.58E-5 β = O_3 coefficient = 0.00498 ΔO_3 = change in daily 12-hour average O_3 concentration (ppb) pop = population of all ages	Study: (Burnett, Cakmak, Brook, & Krewski, 1997) (Burnett, Smith-Doiron, Stieb, Cakmak, & Brook, 1999) Location: Toronto, ON Other pollutants in model: $PM_{2.5\text{-}10}$, NO_2, SO_2

Health endpoint	CR function	Source of CR function
	σ_β = standard error of β = 0.00106	
Hospital admissions – asthma	$$\Delta Asthma = -[y_0 \cdot (e^{-\beta \cdot \Delta O_3} - 1)] \cdot pop$$ where: y_0 = daily hospital admission rate for asthma per person = 4.75E-6 β = O_3 coefficient = 0.00250 ΔO_3 = change in daily average O_3 concentration (ppb) pop = population of all ages σ_β = standard error of β = 0.000718	Study: (Burnett, Smith-Doiron, Stieb, Cakmak, & Brook, 1999) Location: Toronto, ON Other pollutants in model: $PM_{2.5\text{-}10}$, CO
Hospital admissions – obstructive lung disease	$$\Delta Obstruct\ lung = -[y_0 \cdot (e^{-\beta \cdot \Delta O_3} - 1)] \cdot pop$$ where: y_0 = daily hospital admission rate for obstructive lung disease per person = 5.76E-6 β = O_3 coefficient = 0.00303 ΔO_3 = change in daily average O_3 concentration (ppb) pop = population of all ages σ_β = standard error of β = 0.00110	Study: (Burnett, Smith-Doiron, Stieb, Cakmak, & Brook, 1999) Location: Toronto, ON Other pollutants in model: $PM_{2.5\text{-}10}$, CO
Hospital admissions – respiratory infection	$$\Delta Resp\ infection = -[y_0 \cdot (e^{-\beta \cdot \Delta O_3} - 1)] \cdot pop$$ where: y_0 = daily hospital admission rate for respiratory infector per person = 1.56E-5 β = O_3 coefficient = 0.00198	Study: (Burnett, Smith-Doiron, Stieb, Cakmak, & Brook, 1999) Location: Toronto, ON Other pollutants in model: $PM_{2.5}$, NO_2

Health endpoint	CR function	Source of CR function
	ΔO_3 = change in daily average O_3 concentration (ppb) pop = population of all ages σ_β = standard error of β= 0.000520	

SOURCE: (United States Environmental Protection Agency, 1999)

IOMLIFET

IOMLIFET is a spreadsheet system for life-table calculations developed by the Institute of Occupational Medicine for health impact assessment (IOM). IOMLIFET uses standard life-table methods to calculate time-based mortality impacts of changes in mortality risk rates. It can compare the impacts of mortality of various causes (e.g. road traffic accidents, particulate air pollution).

Appendix conclusions and recommendations on methods

Evaluating health impacts of GHG mitigation strategies is a complex process that requires the integration of multiple disciplines. The different tools described in this section are appropriate for different assessment contexts and various technical and operational considerations (e.g. resource constraints, user accessibility).

The ultimate goal of modeling is to inform policy, and it is important for modellers to iteratively engage policy makers in their work to maximize utility of the modeling efforts. Remais et al. (2014) conducted a review to assess decisions that determine modeling approaches and made the following recommendations:

- Modeling health benefits should involve collaboration with policy-makers from the start. Consultations with policy-makers that focus on identifying potential feasible interventions and policy-relevant outcomes will help focus and maximize the utility of model results in informing policy.

- Policy-makers and scientists from different disciplines should be consulted to ensure that a full range of potential impact pathways is considered.
- Initial stages should also involve identifying uncertainties in the casual pathways. Uncertainty in the modeling process should be characterized explicitly. There are two types of uncertainty: Parametric uncertainty consists of uncertainty in values selected for the model's parameters while structural uncertainty consists of uncertainty in the structure of a model (Webster & Sokolov, 1998). Both parametric and structural uncertainties should be considered (examples shown in Table A 3). These uncertainties should also be evaluated with a single (and where possible, multivariate) deterministic sensitivity analysis.
- To better select strategies to meet policy targets, the time between the implementation of mitigation and the realization of health impacts should be analyzed.
- Explicit criteria should be used to determine the exposure-outcome relationships to be included in the modeling assessment.

Improving assessments of health benefits for GHG mitigation strategies can greatly help policy makers become better informed in forming policies that reduce GHG emissions while maximizing health benefits.

Table A 3 Parametric and structural uncertainties in health benefit modeling assessments conducted by (Friel et al., 2009b; Maizlish et al., 2013; Wilkinson et al., 2009; Woodcock, Givoni, & Morgan, 2013b)

Sector	Parametric uncertainties	Structural uncertainties
Buildings		
Specification of mitigation scenarios	Average value of reduction in GHG emissions due to insulation improvements	Feasible transitions from household fossil fuel combustion to electricity
Estimating exposures	Values of the parameters of building physics model	Occupant behavior and increased consumption of resources given higher consumption of resources given higher end-user efficiency
Estimating health impacts	Values of the pollutants' relative risk coefficients	Pollutants to consider in the assessment
Transportation		
Specification of mitigation scenarios	Percentage increase in the level of active travel (walking and cycling)	Nonlinear "safety in numbers" effect of increase in proportion of cyclists on rates of cyclist injuries; different future "active travel visions"
Estimating exposures	Values of the parameters of the emission–dispersion air pollution model	Reduction of emissions from transport in London are representative for other in London are representative for other European cities; reduction in transport emissions results in proportional reduction in particulate matter
Estimating health impacts	Values of the physical activity–disease relative risk coefficients	Diseases affected by physical activity; linear versus nonlinear relationships between physical activity and health outcomes
Food systems		
Specification of mitigation scenarios	Percentage reduction in livestock production by 2030	Contribution of different livestock to greenhouse emissions and different assumptions about feedstocks
Estimating exposures	Percentage reduction in intake of saturated fat	Full replacement of saturated fats with unsaturated fats
Estimating health impacts	Saturated fat-ischemic heart disease mortality relative risk coefficient	Exposure–health outcome pathways

SOURCE: (Remais et al., 2014)