# TransformTO

## CLIMATE ACTION FOR A HEALTHY, EQUITABLE, PROSPEROUS TORONTO

## Results of Modelling Greenhouse Gas Emissions to 2050

SSG SUSTAINABILITY SOLUTIONS GROUP

whatIf?

April, 2017

# Contents

# Acknowledgements

## Project team

### Modelling Advisory Group (MAG)

## Technical Advisor

Ralph Torrie, *Torrie Smith Associates*

## Project Steering Team

| Name | City of Toronto Affiliation |
|---|---|
| Jane Welsh | *City Planning* |
| Peter Vidicus | *Economic Development* |
| Marco Iacampo | *Environment and Energy Division (EED)* |
| Robert Maxwell | *EED* |
| Rae-Anne Miller | *EED* |
| Jim Kroesen | *Shelter, Support & Housing Administration* |
| Aderonke Akande, Lauralyn Johnston | *Tower Renewal* |
| Sarah Gingrich | *Toronto Public Health* |
| Jesse Coleman | *Transportation Services* |
| John O'Grady | *Toronto Transit Commission* |
| Fernando Carou | *EED* |
| Kris Hornburg | *Solid Waste Management Services* |
| Stewart Dutfield | *EED* |

## Core TransformTO Team

Mark Bekkering, *EED*
Mary Pickering, *TAF*
Linda Swanston, *EED*
Cecilia Fernandez, *EED*
Tamara Tukareli, *EED*
Julie Leach, *TAF*
Tim Ehlich, *TAF*

## Other City and Agency Staff

Mike Wehkind, *City Planning*
Michael Hain, *City Planning*
Sean Severin, *EED*
Nadia Jethoo, *EED*
Jimmy Lu, *TAF*
Charlotte Ueta, *Solid Waste Management Services*
City of Toronto - *Tower Renewal*
Lisa King, *City Planning*
Naz Capano, *Transportation Services*

# Consulting Team

## Sustainability Solutions Group

Jeremy Murphy
Julia Meyer-Macleod
Naomi Devine
Mel de Jager
Yuill Herbert

## whatIf? Technologies

Bastiaan Straatman
Chris Strashok
Deryn Crockett
Marcus Williams
Michael Hoffman

## ARUP

Cameron Thomson
Cameron Talbot-Stern

# Abbreviations

| | |
|---|---|
| AV | Autonomous vehicle |
| BAP | Business as planned scenario |
| BBP | Better Buildings Partnership |
| CO2 | Carbon dioxide |
| CDD | Cooling degree days |
| CH4 | Methane |
| EED | Energy and Environment Division |
| EV | Electric vehicle |
| DE | District energy |
| GHG | Greenhouse gas emissions |
| GPC | Global Protocol for Community Scale Greenhouse Gas Emissions Inventories |
| GWP | Global warming potential |
| HDD | Heating degree days |
| LCS | Low carbon scenario |
| MAC | Marginal abatement curve |
| MAG | Modelling Advisory Group |
| MCA | Multi-criteria analysis |
| NPV | Net present value |
| PV | Photovoltaic |
| **RE** | Renewable energy |
| RNG | Renewable natural gas |
| SCC | Social cost of carbon |
| SSG | Sustainability Solutions Group |
| TAF | The Atmospheric Fund |
| TGS | Toronto Green Standard |
| VKT | Vehicle kilometres travelled |

# Executive Summary

## Purpose of TransformTO

TransformTO: Climate Action for a Prosperous, Equitable and Healthy Toronto is a community-wide, cross-corporate initiative of the City of Toronto and The Atmospheric Fund. TransformTO was designed to engage residents, other stakeholders, experts, and all City operations in identifying ways to reduce Toronto's greenhouse gas emissions (GHGs) by 30 percent by 2020, and by 80 percent by 2050, against 1990 levels.

Through a process of technical modelling, a literature review of co-benefits and co-harms, and community input, TransformTO has identified a viable pathway to 80% reductions by 2050 using currently available technologies.

This pathway identifies opportunities for collaborative and sustained efforts by the City, the private sector, higher levels of government and Toronto residents in achieving the required scale of greenhouse gas reductions.

## Purpose of Report

This report builds on analysis completed in previous documents, which can be found on the TransformTO website:

a.  results from detailed technical modelling of Toronto's core urban systems on a pathway to achieve 80% reduction in GHG emissions over 1990 levels,

b.  results from a literature review on the impact of low carbon actions on health, equity and prosperity,

c.  results of a City-wide engagement and consultation with key stakeholders, and

d.  the findings of an expert Modelling Advisory Committee (MAG).

# Project Approach

The City of Toronto hired Sustainability Solutions Group (SSG) to use technical modelling to:

1. Analyze how GHG emissions would change over time in key sectors including buildings, transportation, waste, energy sources, and land use as a result of current federal, provincial, and municipal policies and programs.

2. Evaluate the potential impact of various low-carbon actions and scenarios such as energy efficiency retrofits, increased walking and cycling and improved transit infrastructure on reducing GHG emissions.

3. Analyze potential co-benefits and co-harms of low carbon actions on public health, the local economy and social equity.

CityInSight, an energy and emissions model developed by SSG and whatIf? Technologies was used to support the analysis. CityInSight uses a GHG accounting framework based on the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), a standard that is designed to enable comparability between cities globally.

The analysis began by considering the drivers that contribute to current greenhouse gas emissions, answering the question "where are we now?" A baseline GHG inventory tabulated emissions resulting from buildings, transportation, energy production, and waste in the year 2011. Emissions associated with changes in land cover and carbon sequestration were not included in this analysis.[1,2]

Two scenarios were defined: Business as Planned (BAP) and Low Carbon Scenario (LCS). The BAP explored energy and emissions projections for the city given current and planned policies and actions by municipal, provincial and federal governments. The LCS explored additional actions in order to achieve an 80% emissions by 2050.[3]

The actions development process for the LCS involved research of low carbon actions and best practices in reducing GHG emissions at the city scale. Arup, (a consulting partner to the project), developed a comprehensive list of

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1 Changes in land cover (from greenfield to brownfield) to 2050 is assumed negligible; new growth is targeted to already developed areas in the form of densification/infill.

2 Annual net carbon sequestration of the City's urban forest accounts for 36,500 t CO2e, less than 0.2% of baseline emissions (Every Tree Counts, City of Toronto, 2013).

3 For a detailed description on scenario types, see: Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: towards a user's guide. Futures, 38(7), 723-739.

actions, drawing from their expertise, and involvement in the development of the C40 Climate Action in Megacities v2.0 & v3.0 reports.[4] This initial list also included details of each action, examples of where the action has been implemented, and a review of the potential co-benefits.

The approaches of reduce-improve-switch and low carbon city planning guided the identification of a final list of actions and the sequencing of actions in CityInSight. The stocks and flows logic underpinning CityInSight reflects the inertia associated with buildings or vehicles as well as the interactivity between actions, so sequencing has an impact on the relative effect of actions in reducing emissions. Actions were implemented beginning in the year 2017 in the LCS.

The final step of the scenarios analysis involved assessing the potential impacts of LCS actions on social, economic and health outcomes.

# TransformTO Results

The results of the TransformTO scenario analysis indicate that deep emissions reductions on the order of 80% or more by 2050 are technically feasible using presently available technologies. In addition to GHG emissions reductions, these actions can result in economic and social benefits aligned with the City's existing strategies.

The results of the analysis for the baseline and two scenarios are summarized in Table 1.

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4    C40's Climate Action in Megacities is available at https://issuu.com/c40cities/docs/cam_3.0_2015

*Table 1. Summary results, GHG emissions (Mt CO2e)[5]*

|  | 1990 | 2011 | 2020 | 2050 | THE GAP IN 2050 |
|---|---|---|---|---|---|
| Baseline & Targets | 27 (baseline) |  | 18.9 (target 30x20) | 5.4 (target 80x50) |  |
| 2011 Inventory |  | 19.7 |  |  |  |
| BAP |  |  | 15.7 | 12.6 | 7.2 |
| % reduction over 1990 |  |  | 42% | 53% |  |
| LCS |  |  | 14.8 | 3.9 | -1.5 |
| % reduction over 1990 |  |  | 45% | 86% |  |

Achieving the City of Toronto's emissions reductions target is dependent firstly on scaling up efforts in existing programs and policies such as the Toronto Green Standard, Better Buildings Partnership, Hi-Rise and HELP, and secondly on introducing additional efforts that will require new investments.

The co-benefits analysis suggests that in addition to achieving the objective of GHG emissions reductions, the actions explored in the LCS can also be an economic development strategy, a healthy city plan, a competitiveness and innovation plan, an active transportation strategy, and an energy plan, all in one. With careful consideration, the LCS approach can be a poverty alleviation strategy, and an inclusion strategy. Many of the emissions reduction actions analyzed synergistically support or contribute to other City objectives on economic development and equity, as illustrated by the examples in Table 2.

5    The BAP numbers were adjusted from those in the 2016 Staff Report to incorporate the impacts of decreased heating degree days (HDD) on energy used in commercial buildings, as the previous results had only applied the change in HDD to residential buildings. As HDD increase, particularly towards 2050, there is a decrease in emissions due to a decrease in space heating, which is partially offset by an increased demand for air conditioning. The update also includes the treatment of GHG emissions from biogas and biodiesel as biogenic emissions, or carbon neutral, and the reclassification of some vehicle classes, which had a minor impact on fuel use in transportation in 2050.

*Table 2. Examples of City strategies or objectives supported or enhanced by the Low Carbon Scenario approach[6,7,8,9,10,11,12]*

| POLICY DIRECTION | THEME | LOW CARBON PATHWAY |
|---|---|---|
| Feeling Congested: Official Plan amendment (2014) | Land-use planning | Supports integration of transit with land-use, active transporation and increased efficiency of goods movement. |
| Toronto Official Plan | Land-use planning | Supports development patterns of compact centres, mobility hubs, and corridors connected by regional transit, enhanced transit, an improved pedestrian environment, improved affordable housing, economic development and new employment opportunities. |
| Collaborating for Competitiveness (2013) | Economic development | Supports business investment and new employment. |
| Toronto Strong Neighbourhood Strategy 2020 | Equity | Provides opportunities to improve quality of life through improved accessibility, housing quality and energy security in neighborhoods. |
| TO Prosperity: Poverty Reduction Strategy. | Poverty | Provides new opportunities for quality employment, enhanced transit and accessibility and improved quality and energy efficiency of housing. |
| Toronto Walking Strategy | Active transportation | Supports increased active transportation, including walking. |
| Active City: Designing for Health | Health | Supports the principles identified as critical to an active city. |

6    City of Toronto. (2014). "Feeling Congested?" Recommended Official Plan amendment for selected transportation policies: Official Plan Comprehensive Review. Retrieved from http://www.toronto.ca/legdocs/mmis/2014/pg/bgrd/backgroundfile-71992.pdf

7    City of Toronto. (2015). Toronto Official Plan. Retrieved April 13, 2017, from http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=03eda07443f36410VgnVCM10000071d60f89RCRD

8    City of Toronto. (2013). Collaborating for competitiveness: A strategic plan for accelerating economic growth and job creation in Toronto. Retrieved from https://www1.toronto.ca/static_files/economic_development_and_culture/docs/Collaborating_for_Competitveness_FINAL-v7.pdf

9    City of Toronto. (2015). Toronto Strong Neighbourhoods Strategy.

10   City of Toronto. (2015). TO Prosperity: Toronto poverty reduction strategy. Retrieved from https://www1.toronto.ca/City%20Of%20Toronto/Social%20Development,%20Finance%20&%20Administration/Strategies/Poverty%20Reduction%20Strategy/PDF/TO_Prosperity_Final2015-reduced.pdf

11   City of Toronto. (2009). Toronto walking strategy. Retrieved from http://www1.toronto.ca/City%20Of%20Toronto/Transportation%20Services/Walking/Files/pdf/walking-strategy.pdf

12   Gladki Planning Associates, & DTAH. (2014). Active City: Designing for Health. Retrieved from http://www1.toronto.ca/City%20Of%20Toronto/Toronto%20Public%20Health/Healthy%20Public%20Policy/Built%20Environment/Files/pdf/ActiveCityReportMay292014.pdf

## There are economic benefits

Many of the actions analyzed deliver significant economic returns. Actions accounting for 67% of the emissions reductions in the LCS result in a net financial savings for each tonne of carbon dioxide reduced, while those responsible for the remaining 33% of the reductions result in a net cost.[13] Barriers exist to realizing some financial opportunities, such as the split incentive, in which one party invests in an action while another realizes the financial return. Many of the actions represent financial opportunities that the City is uniquely able to unlock, for example large-scale energy efficiency retrofits. Some actions also require sustained efforts by other levels of government, such as the electrification of the vehicle fleet.

## New employment opportunities are created

Investments required to support the actions considered in the LCS will generate an estimated 327,000 additional and direct person-years of employment between 2017 and 2050. Many of these will be created in emerging sectors such as energy storage, decentralized energy generation and electric vehicle manufacturing. Some employment will be shifted, for example from fossil fuels to renewable energy, and certain jobs will be made obsolete, such as vehicle mechanics who specialize in combustion engines.

## Energy expenditures will be lower in the long term

In addition to new investment opportunities, the LCS results in lower energy costs for businesses and households. Energy efficiency gains exceed the increased energy costs of fuel switching from natural gas to electricity in most areas of the city by 2050. Dwellings in all but four neighbourhoods experience cost savings for heating, cooling and electricity by 2050. Due to extensive district energy and the use of renewable energy, these costs are also resilient against fluctuations in global commodities.

## Damage from climate change is reduced globally

Damage can be attributed to each tonne of carbon dioxide emitted using economic models and avoided damages associated with climate change are therefore one of the most significant benefits of actions to reduce GHG emissions. These avoided costs, which are of global benefit, are estimated to total $11 billion between 2016 and 2050, using the Social Cost of Carbon accounting method.[14]

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13   The marginal abatement cost analysis is described in Section 6.4. The analysis incorporates a price of carbon beginning at $10/tCO2e in 2018 and climbing to $114/tCO2e by 2050.

14   For a detailed description of the Social Cost of Carbon see Section 6.3.1.

## Health outcomes are improved

As fossil fuels are phased out, many air pollutants will be reduced or eliminated, reducing premature deaths and hospitalizations, which were estimated at 280 and 1,090 respectively in 2014 in Toronto.[15] Other health benefits from reduced air pollution include decreased mortality from cardiovascular disease, and decreased prevalence of asthma and allergic diseases. There are also health benefits resulting from increased levels of active transportation. Kilometres walked or cycled in the LCS increases to just under 2 km per person per day in 2050 versus 0.6 km per person per day in the BAP scenario, an increase of 320%.

## Implementation strategies influence the social and economic benefits

Some social and economic benefits associated with the actions considered in the LCS are dependent on the manner in which actions are implemented. For example, an action requiring a significant capital investment will enhance or decrease equity according to the structure of the investment mechanism. Careful consideration needs to be given to determine which activities should be undertaken by the private sector, the City or other entities, and to whom the returns should be directed.

## Impacts vary by neighbourhood

Impacts of emissions reduction actions are also spatially distributed. Some neighbourhoods benefit to different degrees, depending on the characteristics of the built environment. For example, greater opportunities for financial savings are available in neighbourhoods in which people drive further than in those in which people already walk and cycle for many of their trips.

## Actions need to be considered as part of an integrated energy system

The analysis highlights the importance of the city as an integrated energy system. Actions in one sector influence actions in another sector, with implications for financial returns and GHG emissions reductions. District energy is one of the best examples; if district energy systems are designed without considering the impact of building energy efficiency retrofits, the capacity of the district energy system will be greater than the demand, creating a potential stranded investment and reducing or eliminating the financial opportunity of district energy. There may also be a disincentive for building retrofits if the district energy system is developed prior to the retrofits. As another example, the additional electrical demand resulting from the electrification of the vehicle fleet will require upgrades to the capacity of the distribution system, which can be avoided or minimized if building energy

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15    City of Toronto. (2014). Path to healthier air: Toronto air pollution burden of illness update.

efficiency retrofits and the enhanced building code are introduced in tandem. The importance of considering the urban energy system as an integrated whole requires coordination and innovation in planning and governance structures, which historically have been structured in silos according to specific sectors, such as transportation or buildings.

## *Technology will help, but there is an imperative for action now*

Future technological developments may enable further GHG emissions reductions, for example as the efficiency of solar panels increase, or solar panels are integrated into other building materials. Relying on technological progress has limitations, however, as many of the investments that the City makes or enables today have long term implications, locking in patterns of GHG emissions and locking up capital.

## *Climate change, lowered fuel efficiency standards & dirtier electricity are key risks*

Key risks that could impede the ability of the City to achieve its 2050 target were identified using sensitivity analysis as part of the modelling. Risks include changes in buildings' heating or cooling loads resulting from climatic changes, revised fuel efficiency standards, and increased fossil fuel generation in the Provincial electricity grid, which would jeopardize the emissions reduction value of fuel switching efforts in the building and transportation sectors.

In conclusion, the LCS provides a viable roadmap to Toronto's 80x50 GHG emissions reduction target. The City has already made some progress, but no time should be lost in scaling up the effort.

# Toronto in 2050 following **TransformTO**

## A house in 2050

The average new house built in 2050 is smaller that its counterpart in 2015, reduced from 89 m2 (954 ft2) in 2015 to 53 m2 (570 ft2), and the dwelling is more likely to be an apartment. The house uses just 20% of the energy houses use in 2015 and emits near zero GHG emissions. All new dwellings after 2030 are within walking distance of a subway or light-rail train. The roof is covered with solar photovoltaic (PV) panels, with an average capacity of approximately 4 kW. The dwelling is heated with radiant floors, using waste heat transported through underground pipes from nearby industries; cooling is also provided in the summer through the same pipes.

## Moving around in 2050

In most neighbourhoods, it is easy to walk to a school, park, grocery store, restaurant and other key destinations. Residents are likely to walk or cycle to destinations less than 5 km away. Entire road lanes are physically separated for cyclists and cycling is integrated into the culture of the city. Due to demand, cycling roads are plowed before vehicular roads in the winter. City personal transportation planners visit households to teach residents how to identify their best transportation options for trips for work and leisure, while saving money and increasing convenience. Transit is extensive, with new subway lines and an enhanced bus and train system. There are fewer privately owned-vehicles. Residents have access to shared vehicles that are electric, affordable and autonomous: they can be booked by both young people and the elderly.

# Going to work in 2050

Many more people will walk (17%), cycle (28%) and take transit (23%) to work, while fewer will drive (32%) compared to 2011 (when trips by walking and cycling totaled 12% and vehicular trips were 66% of the total).[1] Drivers are unlikely to own a vehicle, relying on shared autonomous vehicles provided by vehicle-sharing companies. Some people travel to work only four days a week. The workplace incorporates more shared office space and there is less floor space per employee. Offices are energy efficient, designed to high standards of energy performance if new and retrofitted to these standards if not. Indoor environmental quality is improved. The building generates energy from solar PV on the roof and facades, and is likely to be connected to a district energy system for heating and cooling.

# Jobs in 2050

There are many new types of employment in 2050 and the low carbon transition is estimated to directly result in an average of 10,000 new person years of employment per year. A major new industry is focused on upgrading the energy efficiency of buildings. Companies involved in this industry undertake major construction projects for entire neighbourhoods and incorporate expertise in finance, law, construction and engineering. Other sectors that are growing significantly include renewable energy, particularly solar PV, energy storage and district energy. The automotive industry has shifted to produce only electric vehicles.

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1. These percentages refer to trips internal to the City's boundaries only.

"At the 21st Conference of the Parties (COP21) in Paris in late 2015 cities took their place as leaders in responding to the threat of climate change. C40 cities, having already taken more than 10,000 climate actions, demonstrated their leadership in reducing carbon emissions and adapting to climate change, by setting ambitious goals through their commitments to the Compact of Mayors. "

C40 Cities Climate Leadership Group, of which the City of Toronto is a member.

# 1.  Introduction

In 2007, Toronto City Council unanimously adopted city-wide greenhouse gas reduction targets of 30% by 2020 and 80% by 2050, below 1990 levels.  At the same time, Council also adopted 60 recommended actions in the Climate Change Action Plan to move the city in the direction of meeting these goals. Although these actions have been largely initiated, on their own they and at their current scale, they will not achieve Toronto's target for 2050.

TransformTO is a renewal of the effort to achieve these targets. A collaborative effort between the City of Toronto and The Atmospheric Fund, TransformTO engages the community in reducing Toronto's GHG emissions. While the primary objective is to reduce GHG emissions, an integral component of the project was to apply the lens of health, equity and prosperity in assessing emissions reductions actions and strategies.

*At the 21st Conference of the Parties (COP21) in Paris in late 2015 cities took their place as leaders in responding to the threat of climate change. C40 cities,[16] having already taken more than 10,000 climate actions, demonstrated their leadership in reducing carbon emissions and adapting to climate change, by setting ambitious goals through their commitments to the Compact of Mayors.[17]*

TransformTO builds on extensive previous efforts by the City, including the Power to Live Green, Toronto's Sustainable Energy Strategy (2009), the Climate Change Action Plan (2007), the Climate Change Adaptation Plan: Towards a Resilient City (2014), and annual GHG inventories.  In parallel to TranformTO, the City is undertaking ResilientTO, a process to enhance the City's resilience to the impact of climate change and extreme weather.

In December, 2016, the Government of Canada, together with the provinces and territories, launched the Pan-Canadian Framework on Clean Growth and Climate Change. The Pan-Canadian Framework is a plan to achieve a 30% GHG emissions reduction over 2005 levels by 2030, a target to which Canada has committed under the 2015 Paris Agreement. Also in 2016 and prior to the announcement of the Framework, the Government of Ontario's Climate Action Plan was released, describing policies and actions specific to Ontario. The Government of Ontario has a target of 15% reduction below 1990 levels by 2020, 37% by 2030 and 80% by 2050.

The work of the City of Toronto through TransformTO supports and, in many cases, enhances the efforts outlined in both the Pan-Canadian Framework and the Climate Action Plan, providing a detailed pathway to achieve significant GHG emissions reductions.

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16    The City of Toronto is a member of the C40 Cities Climate Leadership Group (C40). C40 connects more than 86 of the world's greatest cities, representing over 650 million people and one quarter of the global economy. Created and led by cities, C40 is focused on tackling climate change and driving urban action that reduces greenhouse gas emissions and climate risks, while increasing the health, wellbeing and economic opportunities of urban citizens.

17    C40 (2016). Unlocking climate action in megacities. Retrieved March, 2017 from: http://www.c40.org/researches/unlocking-climate-action-in-megacities

BLOOR

DUNDAS

KING

# 2.  Project Overview

**SUBCOMMITTEE FORMATION**
*APRIL 2015*
Parks & Environment Subcommittee on Climate Change Mitigation & Adaptation

**TRANSFORMTO CREATED**
*MAY 2015*
Council endorses project between TAF & City of Toronto Environment & Energy Division

**COMMUNITY ENGAGEMENT I**
*MARCH 2015 - JULY 2016*
Over 2000 Toronto residents provide views on low-carbon priorities

**REPORT TO CITY COUNCIL**
*DECEMBER 2016*
Report #1: Short-Term Strategies and 2050 Pathway Building Blocks

**TECHNICAL SCENARIO MODELLING**
*JUNE 2016 - MARCH 2017*
Scenario developed showing how to meet City's 2050 target

**COMMUNITY ENGAGEMENT II**
*AUGUST 2016 - MAY 2017*
Continued stakeholder and community engagement

**RECOMMENDATIONS TO CITY COUNCIL**
*MAY 2017*
Report #2: Long-Term 2050 Roadmap

**IMPLEMENTATION**
*JUNE 2017 - 2020*
Implementation of short-term strategies

**IMPLEMENTATION**
*2017 - 2050*
Implementation of 2050 Roadmap

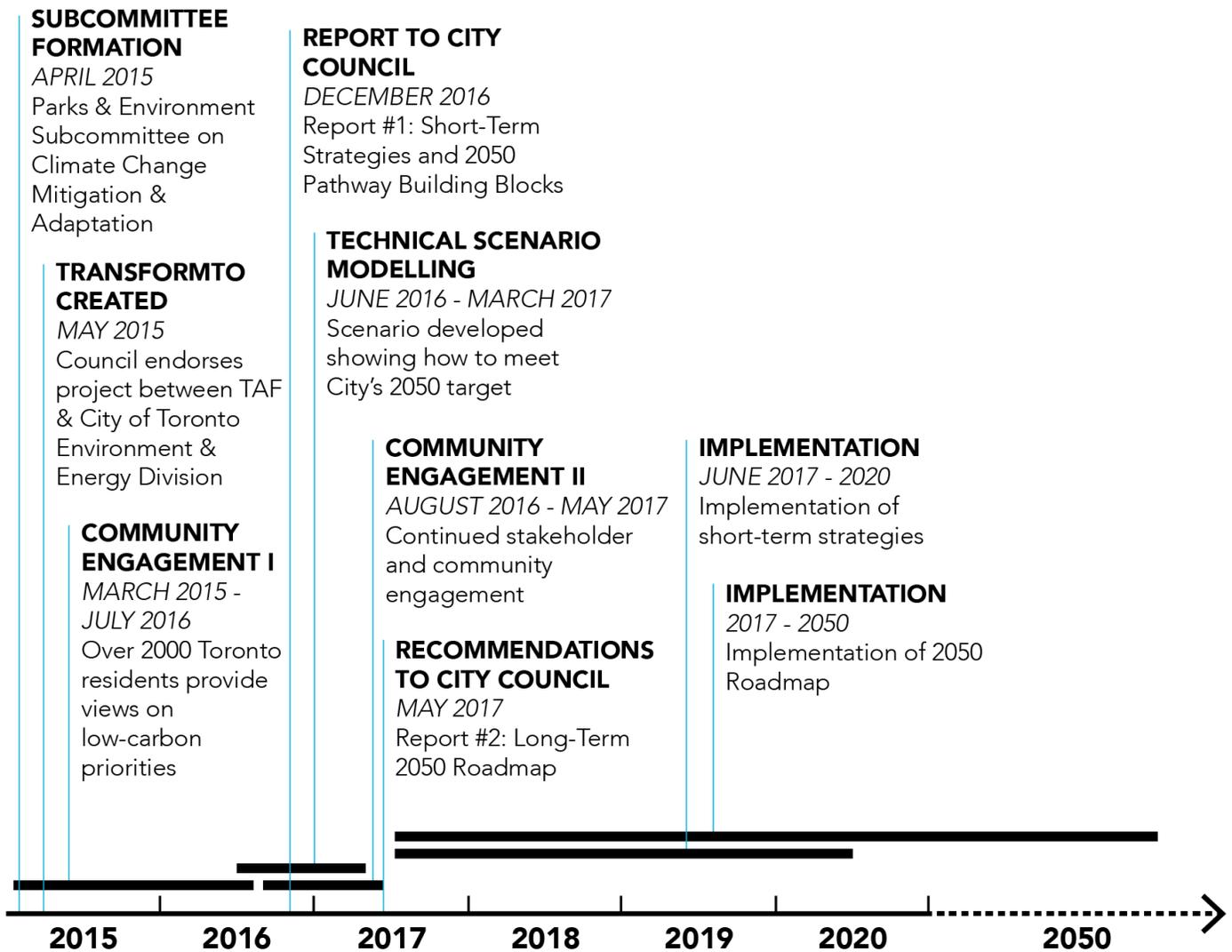2015    2016    2017    2018    2019    2020    2050

*Figure 1. TransformTO timeline*

TransformTO included three key components:

1.  A community consultation process coordinated by the City;

2.  Stakeholder engagement including the Staff Project Steering Team and the Modelling Advisory Group, both of which informed the technical analysis; and

3.  Technical modelling and community benefit research led by SSG working with whatIf? Technologies.

## Community consultation

Over 2000 members of the public were engaged early in the process to support the identification of actions to include in the scenario modelling exercises, priority areas of action, and ways in which community would like to participate in Toronto's low-carbon transformation. A Community Engagement Report described the contributions from the community at large, and these informed the selection of carbon actions modelled during the technical phase.

## Stakeholder engagement

Two groups were formed to support the project, including:

- *Staff Project Steering Team*: A team of 20 inter-divisional staff assembled regularly to draw on their experience in designing and implementing existing climate initiatives, to contribute their knowledge and data sets, and to align proposed TransformTO action with existing strategic plans.
- *Modelling Advisory Group (MAG)*: Over the course of a year, a group of 10 inter-divisional City staff and 25 community members with knowledge of public health, local economy, and equity issues oversaw the modelling research, reviewed and refined draft results, and made recommendations to the overall project.

## Technical modelling & community benefit research

Two scenarios were developed and analysed to evaluate their impacts on energy, emissions and community benefits:

- *The Business-As-Planned (BAP) Scenario* evaluated the results of all currently planned low-carbon actions out to 2050.
- *The Low Carbon Scenario (LCS)* modelled the potential of 36 actions to reduce GHG emissions. The LCS was informed by the

TransformTO community conversations, the Modelling Advisory Group, and meetings with City of Toronto divisions.

The technical scenario modelling resulted in a series of technical papers including: Technical Backgrounder (October 2016); A Business As Planned (BAP) 2050 Scenario (November 2016); and A Low-Carbon 2050 Scenario (January 2017).

Analysis of the potential community benefits of the LCS was based on a literature review titled Consideration of Co-benefits and Co-harms Associated with Low Carbon Actions for TransformTO and an evaluation by the MAG using multi-criteria analysis.[18]

The community engagement and technical analysis have informed two staff reports to Toronto City Council; a report on short term strategies to achieve the City's 2020 target and a long-term 2050 roadmap.

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18    See Section 6.5 for further details.

# 3.  Method

## 3.1  Analysing current conditions

The first step in the analysis was to construct a detailed representation of the current conditions in the City of Toronto. GHG emissions are the result of human activity, including climatic conditions, population characteristics, economic activity, the construction and operations of buildings, movement around the city, the production of solid waste, and other variables. Many activities are interrelated. As an example, the density of dwellings and commercial buildings influences rates of walking and cycling and the potential for district energy.

Understanding the current energy and emissions context required identifying and quantifying the components of the city. How many dwellings are there? What is the floor area and surface area of the dwellings? How are the dwellings heated and cooled? How many people live in the dwellings? Understanding the relationships between the components was also critical. How does the location of dwellings impact ridership on the subway? How does the surface area of the dwelling impact natural gas consumption?

An extensive data collection process was led by the City on each of the dimensions of the urban energy system.  A number of City of Toronto Divisions and City of Toronto Agencies, Boards and Committees provided data and participated in project review meetings, including the following:

- City Planning
- Economic Development & Culture
- Parks, Forestry and Recreation
- Social Development, Finance & Administration
- Solid Waste Management Services
- Toronto Community Housing Corporation
- Toronto Transit Commission
- Toronto Water
- Transportation Services
- Metrolinx
- Waterfront Secretariat

A list of key city documents that were reviewed as part of this analysis are described in Appendix 1.
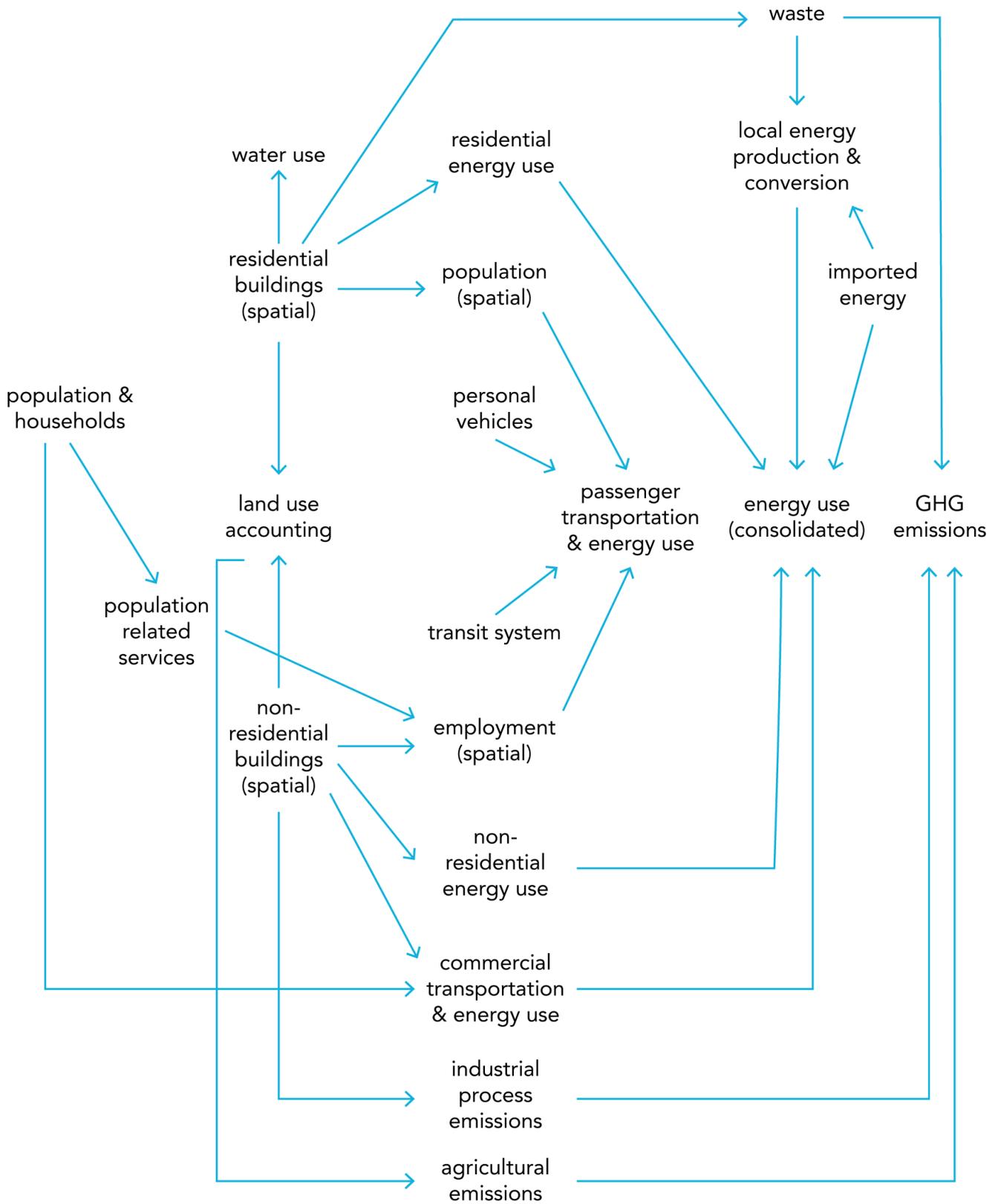
*Figure 2. A systems diagram of drivers of urban emissions*

## 3.2  Modelling

A city's energy systems are highly complex, requiring a sophisticated model to track all of the variables and their relationships. CityInSight is a comprehensive energy, emissions and finance model developed by Sustainability Solutions Group (SSG) and whatIf? Technologies Inc. (whatIf?), and was used for this project.[19] It applies the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC) framework, a global standard designed to enable international comparability between cities.

A representation of the city's energy and emissions was developed for 2011—the baseline year. This involved calibration of the components of the model with observed data. As an example of this process, the total electricity consumption from each end-use for each building—including heating, cooling, appliances, and others—was adjusted until the sum of all the electricity consumption from the buildings was equal to the total electricity consumption reported by the electricity utility. This process of calibration was applied to each sector within the model.

The 2011 baseline inventory includes GHG emissions from buildings, transportation, energy production, and solid and liquid waste. GHG emissions associated with change in land cover and sequestration are not included.[20,21]

The modelling process gives careful attention to the useful lifetimes of different capital assets, using the concept of stocks and flows. For example, CityInSight tracks the stock of vehicles by type and by vintage; the flow consists of the retirement of vehicles as they reach the end of their life and new vehicles are added to the stock. This consideration is present in each sector within the model for stocks such as buildings, equipment and infrastructure.

The concept of stocks and flows has significant implications for the cost of the LCS. For example, if a natural gas boiler is replaced at the end of its useful lifetime with a heat pump, the cost associated is significantly lower than if the natural gas boiler is replaced prior to the end of its useful life. Different types of equipment turn over more quickly than others. Equipment such as trains for the transit system and industrial boilers will likely be replaced just once between now and 2050. Buildings are likely to last well beyond 2050. Light fixtures will be replaced three to five times. Implementing the policies and actions of the LCS as soon as possible is critical to avoiding increased costs associated with early replacement, particularly for longer lasting assets.

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19   For detailed information on the modelling approach, refer to Modelling Toronto's Low Carbon Future: Data, Methods and Assumptions Manual (DMA).

20   Changes in land cover (from greenfield to brownfield) to 2050 is assumed negligible; new growth is targeted to already developed areas in the form of densification/infill.

21   Annual net carbon sequestration of the City's urban forest accounts for 36,500 t CO2e, less than 0.2% of baseline emissions (*Every Tree Counts, City of Toronto, 2013*).

## 3.2.1  2011 - the base year

In the baseline year, buildings account for 56% of GHG emissions in the City, followed by transportation at 31%.

TOTAL EMISSIONS BY SECTOR, 2011
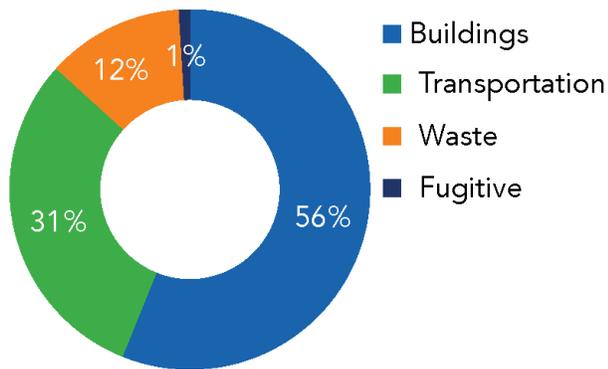
TOTAL EMISSIONS BY FUEL, 2011
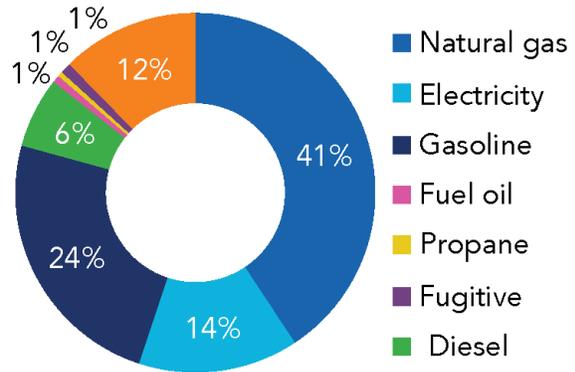


*Figure 3. Two views on GHG emissions in 2011.*

Of the emissions within buildings and transport, natural gas accounts for 41%. As an energy source, natural gas is both the largest contributor to total emissions within the buildings sector, and the city overall.  Gasoline is the second largest contributor at 24%, and the largest contributor to emissions within the transportation sector.

## 3.3   What does the future hold?

Two scenarios were developed to explore possible futures for the City of Toronto. Scenarios are not predictions but are stories about how the world will or may change at some future time. A scenario is defined as a state at a future time as imagined in the present.

As applied in the context of TransformTO, scenario planning serves multiple purposes, including[22]:

- A decision tool - "future proofing" a portfolio of activities and proposed actions;

- A prioritization tool - determining where and how to allocate finite resources;

- A testing tool - using multiple "settings" to strengthen an existing strategy, innovation initiative or priority;

- An oversight tool - adding perspective and insight to other planning processes;

- An integrative tool - applying judgment to complexity for making sense of the world;

- A generative tool - producing innovative ideas, programs, products, and services;

- A timing tool - reacting appropriately (i.e. neither overreacting nor underreacting);

- A scanning tool - monitoring for deeper shifts in the external environment;

- A proactive tool - combating reactive demands; taking affirmative steps to prepare for the future; and

- A conversation tool - talking about difficulties in a safe (hypothetical) way.

Two scenarios were developed for the City of Toronto that continue from the baseline of 2011 out until 2050. The *Business as Planned (BAP)* scenario explores the question of what will happen to energy and emissions for the city given current and planned policies and actions at all levels by municipal, provincial and federal governments. The *Low Carbon scenario (LCS)* explores what can happen if certain actions are put in places, but is also goal-oriented, in that it seeks to achieve the objective of 80% reduction in GHG emissions by 2050.[23]

---

22    Smith, E. (2007). Using a scenario approach: From business to regional futures. Engaging the future: Forecasts, scenarios, plans, and projects, 79-101.

23    For a detailed description on scenario types, see: Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: towards a user's guide. Futures, 38(7), 723-739.

In developing the BAP and the LCS, the following design characteristics were applied:

- Plausibility. The scenarios must be believable, reflecting current conditions and future trajectories that are intuitive;

- Relevance. The scenarios must provide additional insights to decision-makers on key strategic issues and decisions at hand;

- Challenging. The scenarios must make one think about conventional wisdom, and give rise to different possibilities and options;

- Divergence. Together, the scenarios should "stretch" the thinking about the future environment, so that the decisions take account of a wider range of issues;

- Balanced. The scenarios should strike a balance between challenges and opportunities, risks, and upside potential.

## 3.4   Conceptualizing scenarios

The two scenarios were developed in close consultation with many different Divisions in the City of Toronto (see section 3.1). These discussions helped inform the representation of current and planned policies and actions within the model and the identification of potential policies and actions, drawing on the experience, observations and wisdom of City staff. The results of the community and stakeholder engagement process also informed the framing and development of the two scenarios.

### 3.4.1  The BAP: A representation of status quo

Modelling and analysis was undertaken to develop an emissions baseline and BAP scenario in order to understand the drivers of emissions in the City, to reflect the current and future context of the City of Toronto and to inform the development of actions to further reduce emissions.

The BAP projection covers the time period between the baseline year and 2050. The BAP is designed to illustrate energy use and greenhouse gas emissions for the City of Toronto if no additional policies, actions or strategies are implemented. The BAP reflects plans, policies, programs and/ or projects at the municipal, provincial and federal levels that have been funded, such as increased application of the Toronto Green Standard or are currently being implemented, such as the CAFE Standards for Light-Duty Vehicles. A projection for the uptake of electric vehicles in Ontario was included in the BAP, but no other impacts from the Ontario Climate Action Plan were included, as the details of the initiatives and how they overlap with existing policies and programs were not available when this report was being published.[24]

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24    A description of the assumptions is in the report titled Modelling Toronto's Low Carbon Future: BAP results, available at: http://www1.toronto.ca/City%20Of%20Toronto/Environment%20and%20Energy/Climate%20and%20Energy%20Goals/Transform%20TO/PDFs/REPORTS/SSG%20Reports/161110_Final%20TechPaper1_BAP.pdf

In total, the population of the city is projected to increase from 2.721 million in 2011[25] to 3.497 million in 2050 and total employment increases from 1.572 million in 2011 to 2.69 million over the same period.

## POPULATION AND EMPLOYMENT IN THE CITY OF TORONTO, 2016 - 2051
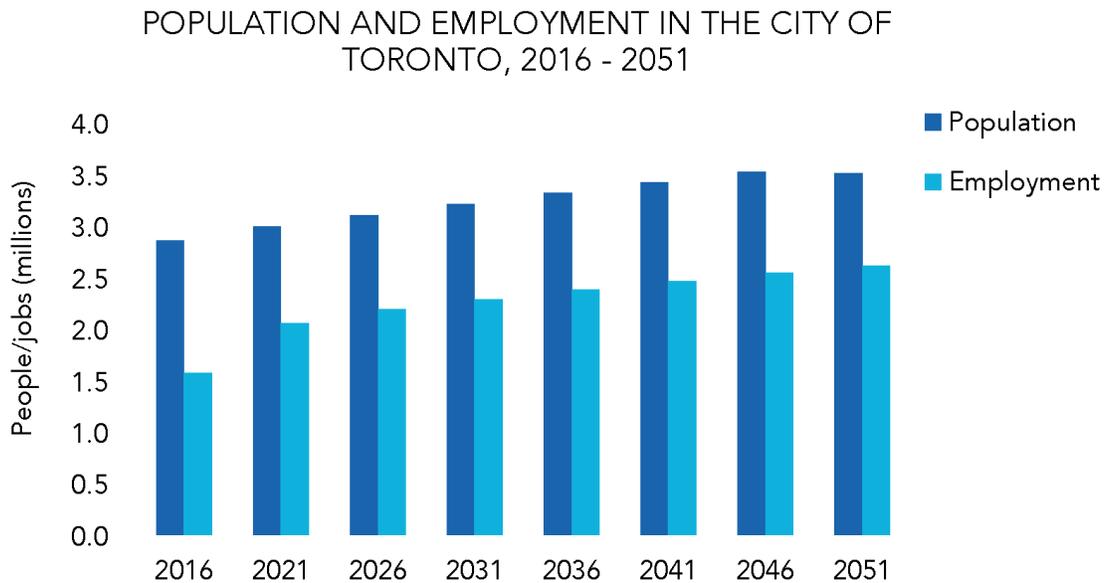


*Figure 4. Population and employment projections, 2016-2051.*

The population projection was analysed spatially and in general. Overlap is evident between projected future development and the planned transit system, indicating a pattern of intensification consistent with the objectives of the Official Plan. Figure 4 illustrates population and employment density in 2050 in relation to the planned transit system. Shading that represents high population and employment density corresponds with thresholds which support higher orders of transit.[26] At densities of 200-400 people and jobs per hectare, bus rapid transit or light rail transit is preferred and at greater densities than 400 people and jobs per hectare, subway is preferred.

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25   This estimate accounts for census undercount and external students.

26   Higgins, C. D. (2016). Benchmarking, planning, and promoting transit-oriented intensification in rapid transit station areas. Retrieved from https://macsphere.mcmaster.ca/handle/11375/20228

Legend

2051 Density by zone (people + jobs) / ha

- 0 - 125
- 125 - 200
- 200 - 400  (BRT/LRT is supported)
- 400 - 3199 (subway is supported)

Current and proposed transit

- Subway
- GO transit
- Bus rapid transit
- Light rail transit
- Rapid transit
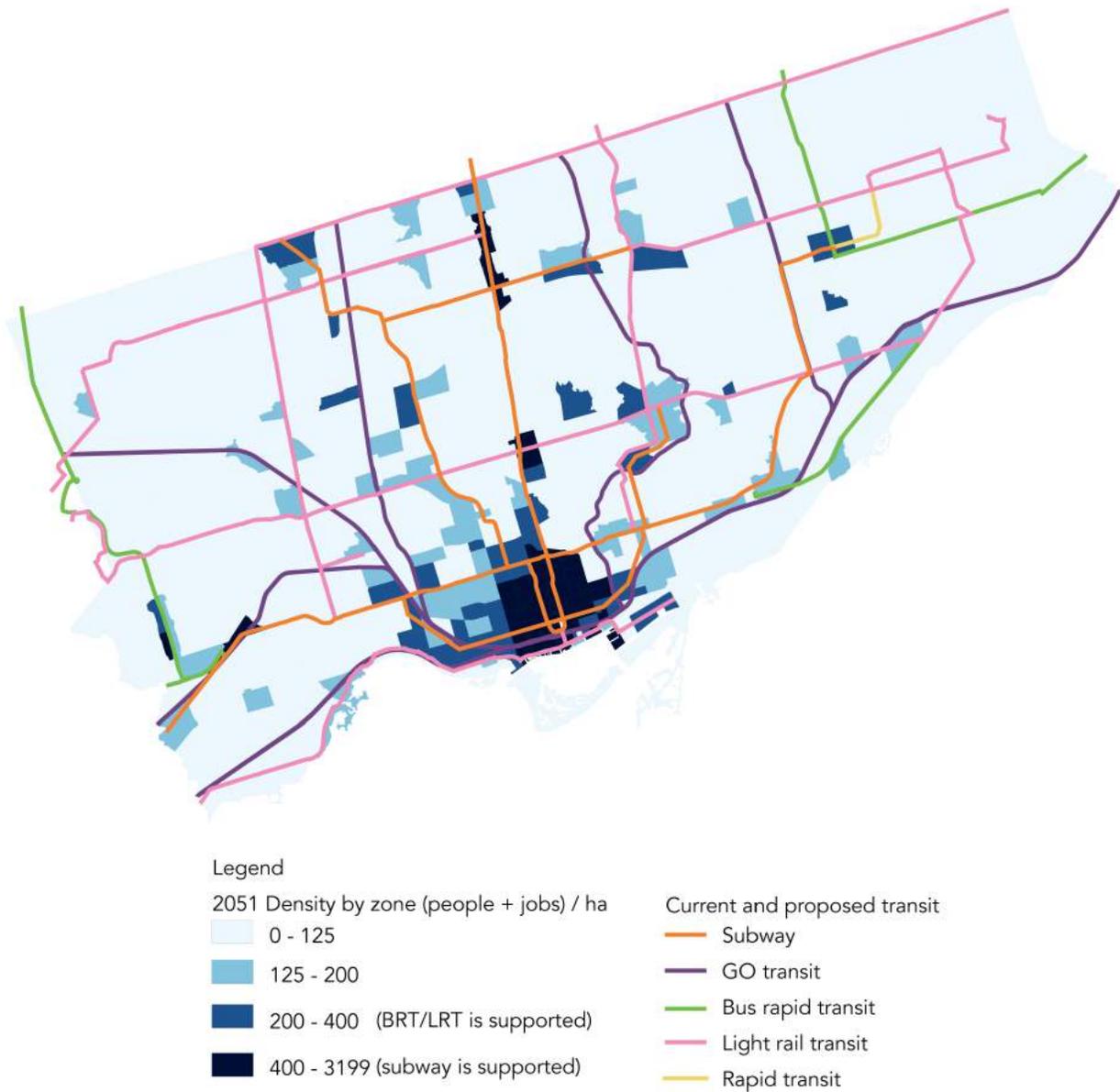
*Figure 5. Relationship between density (people and jobs) and the projected transit system.*

GHG emissions and energy consumption were analyzed in detail for the BAP scenario and the results are discussed in the report titled Modelling Toronto's Low Carbon Future: BAP Results. GHG emissions have a decreasing trajectory, amounting to 15.7 Mt CO2e in 2020, and 12.6 Mt CO2e in 2050, as illustrated in Figure 6.[27]

---

27  The BAP numbers were adjusted from those in the 2016 Staff Report to incorporate the impacts of decreased heating degree days (HDD) on energy used in commercial buildings, as the previous results had only applied the change in HDD to residential buildings. As HDD increase, particularly towards 2050, there is a decrease in emissions due to a decrease in space heating, which is partially offset by an increased demand for air conditioning. The update also includes the treatment of GHG emissions from biogas and biodiesel as biogenic emissions, or carbon neutral, and the reclassification of some vehicle classes, which had a minor impact on fuel use in transportation.

## PROJECTED GHG EMISSIONS BY SECTOR (MT CO2e)



*Figure 6. BAP - Projected GHG emissions by sector (MT CO2e).*

The primary drivers of the projected reduction in total GHG emissions between the baseline year and 2050 include[28]:

- Decline of grid electricity emissions factor, particularly over the period of 2012 to 2016 as coal generation was phased out in the electricity grid;

- Improving vehicle fuel efficiency standards;

- Decrease in heating degree days (due to a warming climate), partially offset by an increase in cooling degree days (Figure 7);

- Increase in energy retrofits of existing buildings;

- Increased efficiency in new construction;

- Increasing numbers of electric vehicles in overall stock of vehicles; and

- Increasing diversion rates in solid waste.

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28    For details, refer to Technical Paper #1: BAP Results.

PROJECTED IMPACT OF CLIMATE CHANGE ON HEATING AND
COOLING IN THE CITY OF TORONTO, 2000 - 2049
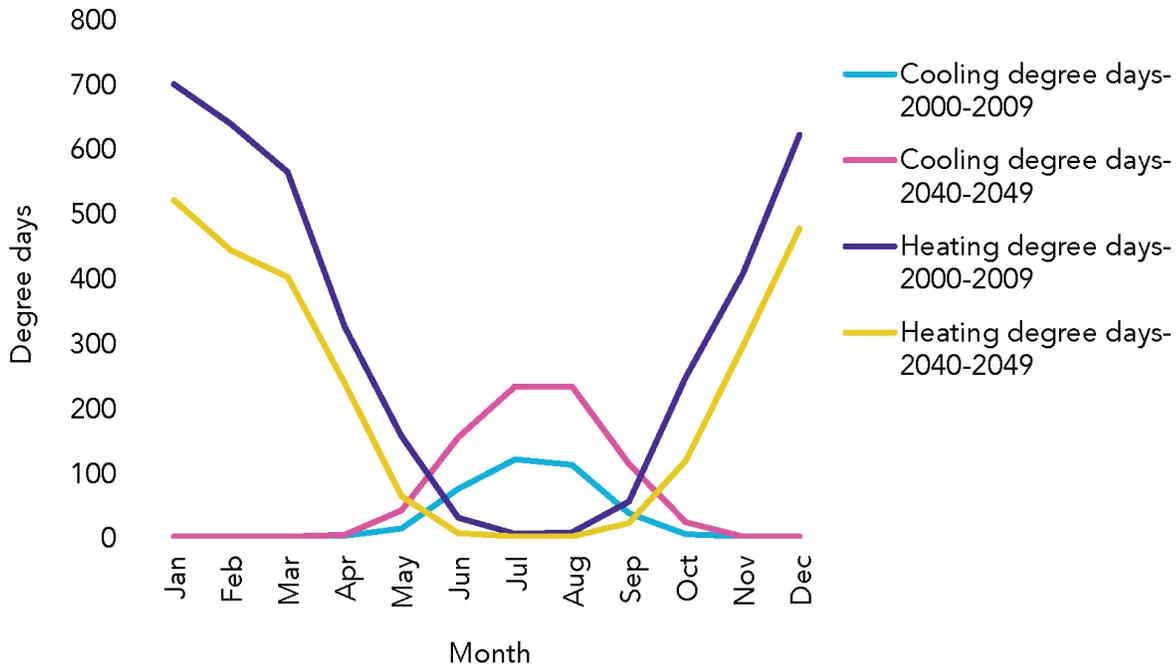


*Figure 7. Heating and cooling degree days in 2000-2009 and 2040-2049[29]*

While the BAP projects a declining trajectory, the City's 80x50 target (5.4 Mt CO2e) will not be achieved without additional effort, above what was assumed in the BAP, as illustrated in Figure 8.
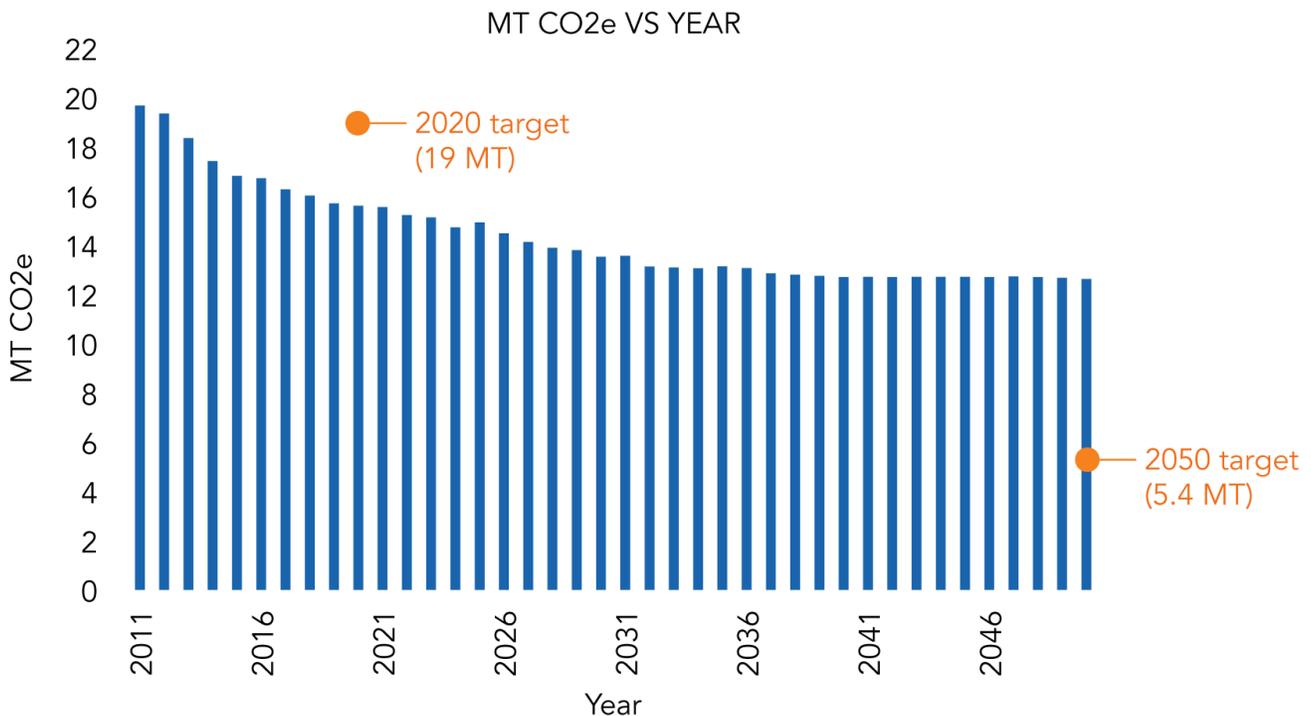


*Figure 8. Annual GHG emissions for the BAP, including the 2011 baseline.*

29    SENES Consultants Ltd. (2011). Toronto's future weather and climate driver study: Volume 2- data tables (200-2009 and 2040-2049). City of Toronto. Retrieved from http://www1.toronto.ca/city_of_toronto/environment_and_energy/key_priorities/files/pdf/tfwcds-volume2-datatables.pdf

## 3.4.2  The Low Carbon Scenario

The LCS explores a potential pathway for achieving Toronto's 2050 target, reducing emissions by 80% by 2050 over 1990 levels, known as 80x50. The modelling and quantification of reduction potentials of key low carbon actions to support this effort are further detailed in Technical Paper #3: 80x50 Low Carbon Scenario, available on TransformTO's website.

A key aspect of low carbon planning is prioritizing interventions using a hierarchy based on what lasts longest.[30] The first priority is land use planning and infrastructure, including density, mix of land uses, energy supply infrastructure and transportation infrastructure. The second priority is major production processes, transportation modes and buildings, including industrial process, choice of transportation modes, and building and site design. The final priority is energy-using equipment including transit vehicles, motors, appliances and HVAC systems.

This hierarchy explicitly concentrates the efforts on spheres of influence where there are fewer options to intervene between now and 2050, and it decreases the emphasis on the easier interventions which are likely to have greater short term returns. The World Bank defines this consideration in terms of urgency[31];  posing the question: "Is the option associated with high economic inertia such as a risk of costly lock-in, irreversibility, or higher costs, if action is delayed or not? If the answer is yes, then action is urgent; if not, it can be postponed." From this perspective, land-use planning and major infrastructure investments are the more urgent mitigation option.

The City of Toronto has a community energy planning (CEP) program[32], which is focused on considering energy early in the land-use and infrastructure planning process for an area and identifying opportunities to integrate local energy solutions at the building and neighbourhood-scale. This program focuses on developing low-carbon thermal energy and electricity generation solutions at the building and neighbourhood-scale, alleviating constraints in energy infrastructure through conservation and local sources of low-carbon energy, energy resilience and local economic benefit.

Complementary to the low carbon planning hierarchy is the approach of reduce, improve and switch. This approach, which we have adapted from similar approaches such as the well-known Reduce-Reuse-Recycle (from the

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30   Jaccard, M., Failing, L., & Berry, T. (1997). From equipment to infrastructure: community energy management and greenhouse gas emission reduction. Energy Policy, 25(13), 1065–1074.

31   Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. M. (2015). *Decarbonizing development: three steps to a zero-carbon future*. Washington, DC: World Bank Group.

32   City of Toronto. (2016). *Community Energy Planning*. Retrieved from http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=4c096d820a926410VgnVCM10000071d60f89RCRD

waste sector), and Avoid-Shift-Improve[33] (from the transportation sector), seeks to consider the energy system as a whole in all sectors. It focuses on the concept of reducing energy consumption, improving the efficiency of the energy system (supply and demand), and then fuel switching to low carbon or zero carbon renewable sources.

The energy system is complex, and the linear application of reduce-improve-switch is not simple; neither should it be the only approach considered. Many actions have cross-cutting impacts; for example, building retrofits can reduce the amount of energy required for space heating through envelope improvements, and improve the efficiency of the energy used in the building through equipment upgrades. Solar PV could be installed on the roof at the same time, facilitating a switch to a zero carbon renewable source. In general, whether it be buildings, transport or waste, the focus is to first reduce the amount of energy required by as much as possible through reduced consumption and efficiencies, and then to fuel switch to low or zero carbon fuel source for the remainder of the demand.

The concepts and approaches of reduce-improve-switch and low carbon planning described above guided the analysis and identification of a final list of actions for modelling, as well as the sequencing of actions in modelling.

The actions in the LCS were informed by the results of three previous parts of the project: The first part of the actions development process involved extensive research of low carbon actions and best practices to reduce emissions at the city scale. Arup, a consulting partner to the project, conducted a comprehensive search of actions from a number of sources, leveraging their particular expertise and involvement in the development of the C40 Climate Action in Megacities v2.0 & v3.0 reports. This work resulted in an "initial" long list of actions and included details of each action, examples of where it has been implemented, and an initial review of the potential co-benefits. Actions were implemented beginning in the year 2017 in the LCS.

The initial list was reviewed with City staff, and a filtering process was undertaken to identify actions that were not relevant or applicable to the context of the City, or that the City was already undertaking. In addition, the actions were reviewed in the context of the engagement results, undertaken as part of the TransformTO project in 2015-2016.

This initial list of actions was completed prior to the baseline and BAP emissions modelling and was therefore agnostic as to whether the implementation of the action would have a significant impact on emissions reduction in the City context or not; this approach was intentional so that no action was left off the initial list.

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33   GIZ. (2011). Sustainable urban transport: Avoid-shift-improve. Retrieved from http://www.sutp.org/files/contents/documents/resources/E_Fact-Sheets-and-Policy-Briefs/SUTP_GIZ_FS_Avoid-Shift-Improve_EN.pdf

The LCS focuses on existing technologies without incorporating any assumptions around the development and deployment of new technologies. Any additional beneficial developments in low carbon technologies between now and 2050 will therefore ease the pathway to the 80% target.

*Table 3. In the numbers[34,35]*

| INDICATOR | BASELINE, 2011 | BAP, 2050 | LCS, 2050 | UNITS |
|---|---|---|---|---|
| Total GHG emissions | 19,672,500 | 12,580,000 | 3,911,000 | tCO2e |
| GHG per person | 7.46 | 3.50 | 1.09 | tCO2e |
| Floor area per dwelling | 101 | 89 | 53 | m2 |
| Non-residential space per person | 50.7 | 43 | 42.6 | m2 |
| % of internal trips by car | 66 | 60 | 32 | % |
| VKT per person | 5,405 | 4580 | 4,429 | Km |
| Average energy costs per dwelling | $3,387 | $2,825 | $1,674 | $/household |
| Solid waste to landfill per person | 0.19 | 0.2 | 0.03 | tonnes |

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34    Internal trips refer to trips within the city boundary.

35    Energy costs per dwelling include annual energy costs for heating, cooling, electricity, transportation and the associated price of carbon in current dollars.

# 4.  Five urban systems

This section discusses the assumptions and observations associated with the LCS for the five urban systems: land-use, buildings, transportation, energy and waste.

## 4.1  Land-use

*LCS Modelling Assumption: Future development is concentrated in areas appropriate for district energy and accessible to rapid transit.*

Land-use patterns are widely recognized as one of the most important city-scale interventions in reducing GHG emissions because of their cascading effects.[36]  For example, increased density increases the viability of district energy, enhanced transit and the likelihood that people will walk and cycle. On the other hand, future development that results in new floorspace that is not accessible to transit or district energy may increase GHG emissions and energy requirements. Modelling results indicate that the City's Official Plan, over the decades that is has been implemented, has resulted in a focus on intensification, and therefore the major gains in GHG emissions reductions associated with land use have already been achieved.  Existing City policies continue to be supportive of this direction, focusing new development in Downtown, Centres and along Avenues served by transit, as well as protecting transit corridors.[37]  As a result of these policies future development in the City is oriented towards intensification.[38]

An analysis of the projections for development patterns in the BAP confirmed the pattern of intensification along transportation corridors, and identified a relatively small portion of future development occurring in areas without walking access to frequent transit; of all development projected between 2030 and 2050,[39] 14% of non-residential floorspace (1,034,000 m2)  and 10% of residential units (23,630 units) are located in areas beyond 500m to frequent transit routes per the BAP.

To assess the impact of concentrating an even higher portion of future development in areas with walking access to transit, all of the future

36    Seto, K. C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G. C., Dewar, D. et al. (2014). Human settlements, infrastructure and spatial planning. Retrieved from http://pure.iiasa.ac.at/11114/

37    City of Toronto. (2015). Toronto Official Plan. Retrieved from http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=03eda07443f36410VgnVCM10000071d60f89RCRD

38    City of Toronto. (2016). How does the city grow? Retrieved from http://www1.toronto.ca/City%20Of%20Toronto/City%20Planning/SIPA/Files/pdf/Grow/HDCG_2016_Final_accessible.pdf

39    Development prior to 2030 was considered to be difficult to influence because it is likely already in some stage of the planning process.

residential development and 60%[40] of the non-residential floorspace (622,330 m2) projected to develop between 2030 and 2050 in areas without walking access to transit was modelled in transit accessible areas.[41]  In the context of all of the buildings in the city, this is a small amount, just 1.7% of dwellings units and 0.6% of the non-residential floor space.

The importance of land-use interventions was understated in the initial modelling analysis, because the approach did not capture feedback related to other actions such as district energy (which can expand to additional areas if additional density is added), walking and cycling (more trips are shorter as a result of the concentration of future development and there are more opportunities to shift to walking and cycling) and enhanced transit (dwellings are located closer to transit and residents can use it more frequently).

In order to better understand the impact of land use within the related actions, an integrated scenario was run first with all the actions and second with all the actions but without the land use action. The difference between the two scenarios indicates that approximately 60 ktCO2e of additional emissions reductions are realized in various actions when the land-use action is implemented. The majority of these emissions (~ 51ktCO2e) are associated with increased deployment of district energy, as district energy can be implemented in additional locations due to the increased density resulting from redirecting floor space. The remainder of the reductions are the result of reduced vehicular transportation, as more people are able to walk and cycle because they are closer to destinations, including transit.

## *Observations*

The City is planning for and experiencing a high level of intensification. However, approximately 10% of projected residential and non-residential development between 2030 and 2050 is anticipated to occur in areas currently with limited or no access to frequent transit as per the BAP. This 10% of future development, however, represents just 1% of the total building stock, which explains its relatively small impact.

Increasing population density can also increase the heat density of an area so that it surpasses the threshold at which district energy makes sense, tipping the balance. In this way, managing development can be used as a lever to enable district energy for a large number of buildings, an example of how one action can have a much larger impact. Managing growth can also result in the increased density required to support more frequent transit and, vice versa, providing more frequent transit can result in increased density.

---

40    Only 60% of the non-residential floor space was redirected because some of this floor area is required for warehousing, light industrial and other uses that are not appropriate in mixed-use areas.

41    The analysis is limited by the resolution of the zones, as only development in zones that do not overlap with a 500m buffer with transit were considered. There is additional projected development that is beyond 500m in zones that overlap with the 500m buffer and could not be identified at the level of zones.

In addition to the post-2030 period, there may be additional opportunities to manage development to support district energy and walking access to transit in the pre-2030 period. For example, interventions in processes such as the 20-year capital plans or development charge background studies could be explored to encourage and achieve densities that support district energy and public transit.

It is also important to note that if the full build-out of the transit system as illustrated in the Official Plan is not completed, there will be many more residential and non-residential buildings that do not have walking access to transit, beyond the 10% of the post-2030 development considered in this analysis.

## 4.2   Buildings

The inventory of the building stock was adjusted in the LCS to reflect a background rate of demolition, as older buildings are replaced by new buildings. Additionally, a trend toward smaller dwellings and decreased floor space per employee was incorporated, which reduced the total projected floor area of future residential and non-residential buildings.

*LCS Modelling Assumption: New buildings are increasingly efficient – moving to near net zero energy.*

Using the approach of Avoid-Reduce-Replace, the first priority was to avoid generation of emissions by ensuring that the efficiency of new construction minimizes the requirement for, and cost of, future retrofits. The City of Toronto is drafting an update to the Toronto Green Standard (TGS)[42] that includes four tiers of performance introduced stepwise until 2030. In the model, these draft updates of the TGS were applied to new construction, using performance targets developed by the project consultant, Integral Group,[43] with the final tier resulting in energy consumption of approximately 20% of current practice and near zero GHG emissions.[44] An incremental approach was assumed with adoption of the TGS tiers beginning in 2018 and assuming that 100% of all new construction moves towards a zero emissions buildings framework  by 2030, as illustrated in Figure 9.

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42    Information on the TGS can be found at: 5552cc66061410VgnVCM10000071d60f89RCRD" http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=f85552cc66061410VgnVCM10000071d60f89RCRD.

43    Integral Group, Morrison Hershfield, & Provident. (2017). The City of Toronto zero emissions building framework. Draft Report.

44    GHG emissions are near zero because only electricity is used, some of the electricity is generated using solar PV systems and the remainder comes from the electricity grid, which has a low emissions factor.

APPLICABLE NEW BUILDING FLOORSPACE FOR THE CITY OF
TORONTO GREEN STANDARD (TGS), BY STANDARD VERSION, TIER
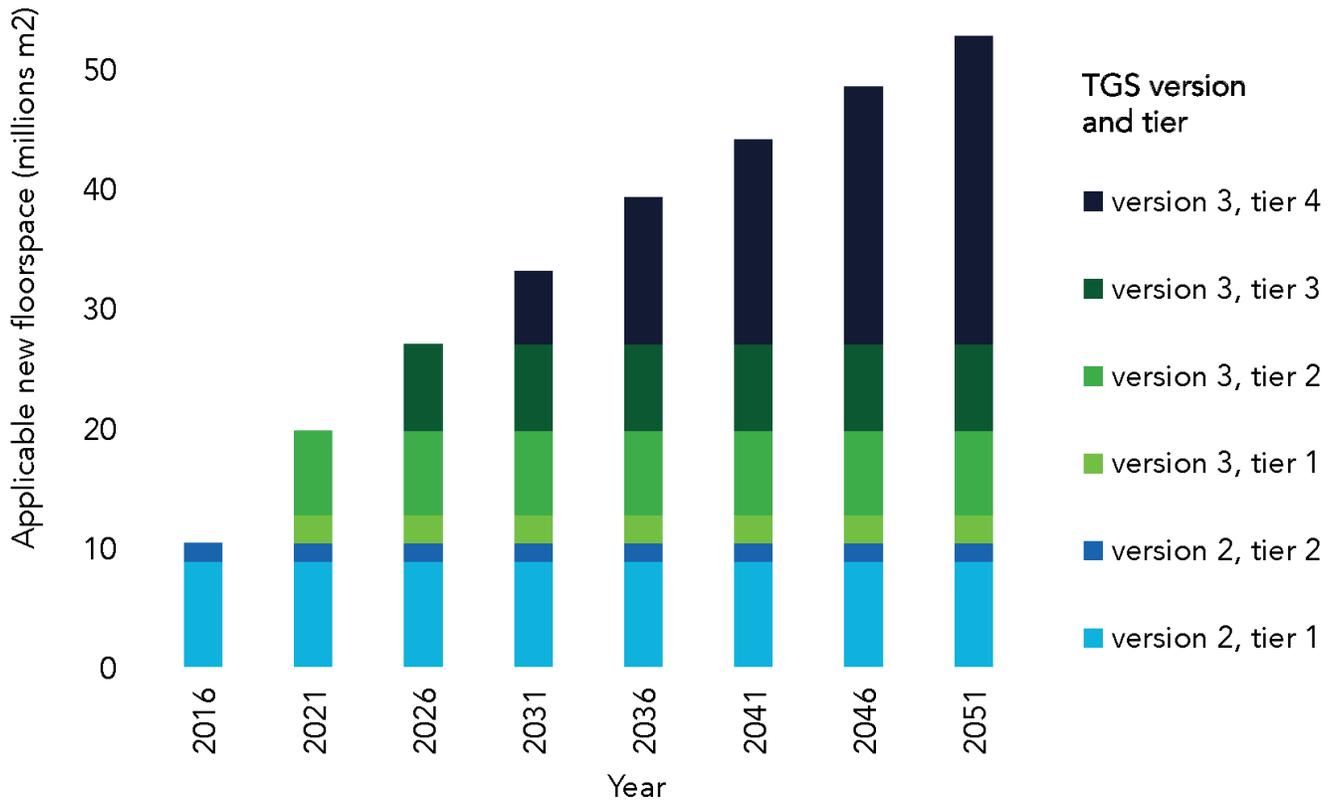AND YEAR FROM 2016 TO 2051



*Figure 9. The application of TGS standards to new buildings post 2016*

*LCS Modelling Assumption: All of the building stock is upgraded including existing stock with increasing efficiency moving to near net zero emissions.*

In addition to new construction, TGS was also applied to renovations, when a building permit is required for structural or material alterations. The building permit requirements trigger an opportunity to enhance energy performance when major expenditures will be made on the building for reasons other than energy efficiency.

Another significant target for energy savings is the existing pre-2016 building stock. In addition to targeting new construction and major renovations. The City of Toronto currently runs retrofit programs targeting different components of the building stock including HELP (for single family homes), Tower Renewal (apartments) and Better Building Partnership (commercial buildings).

The retrofit assumptions, which target savings of 40% for thermal energy and 30% for electricity, are ambitious. The targets are, however, below the threshold that the US National Renewable Energy Laboratory describes as a deep energy retrofit,[45] which results in energy savings of greater than 50%. In the LCS there is a target of 50% savings for thermal energy in the Tower Renewal category, which works with buildings of 5 storeys or more constructed between 1945 and 1984. Savings opportunities were assumed to be higher for thermal energy, as considerable effort has already been invested in savings in electricity in this category of buildings.

The lower line in Figure 10 shows the cumulative increase in the area of buildings retrofit out until 2050, expressed in m2. The upper line shows the total floor area of the pre-2016 building stock, which declines due to demolitions. In terms of number of buildings that this represents, residential building retrofits peak at approximately 480 buildings per year in 2021, declining to under 50 pear year by 2050.

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45    NREL. (2013). Deep Retrofits. Retrieved from https://energy.gov/sites/prod/files/2014/05/f15/deepenergyretrofitsandstateapplications.pdf

RESIDENTIAL RETROFITS AND RENOVATIONS IN THE CITY OF
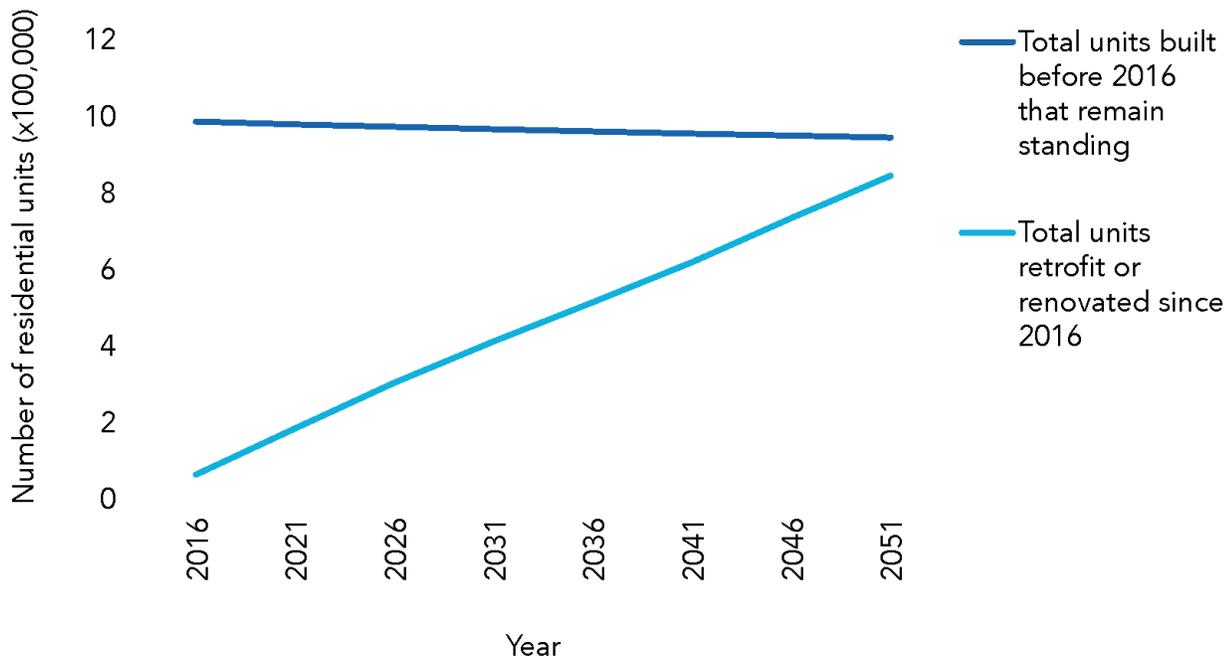TORONTO LOW CARBON SCENARIO, 2016 - 2051



*Figure 10. Number of dwelling units in the city either retrofit or renovated*
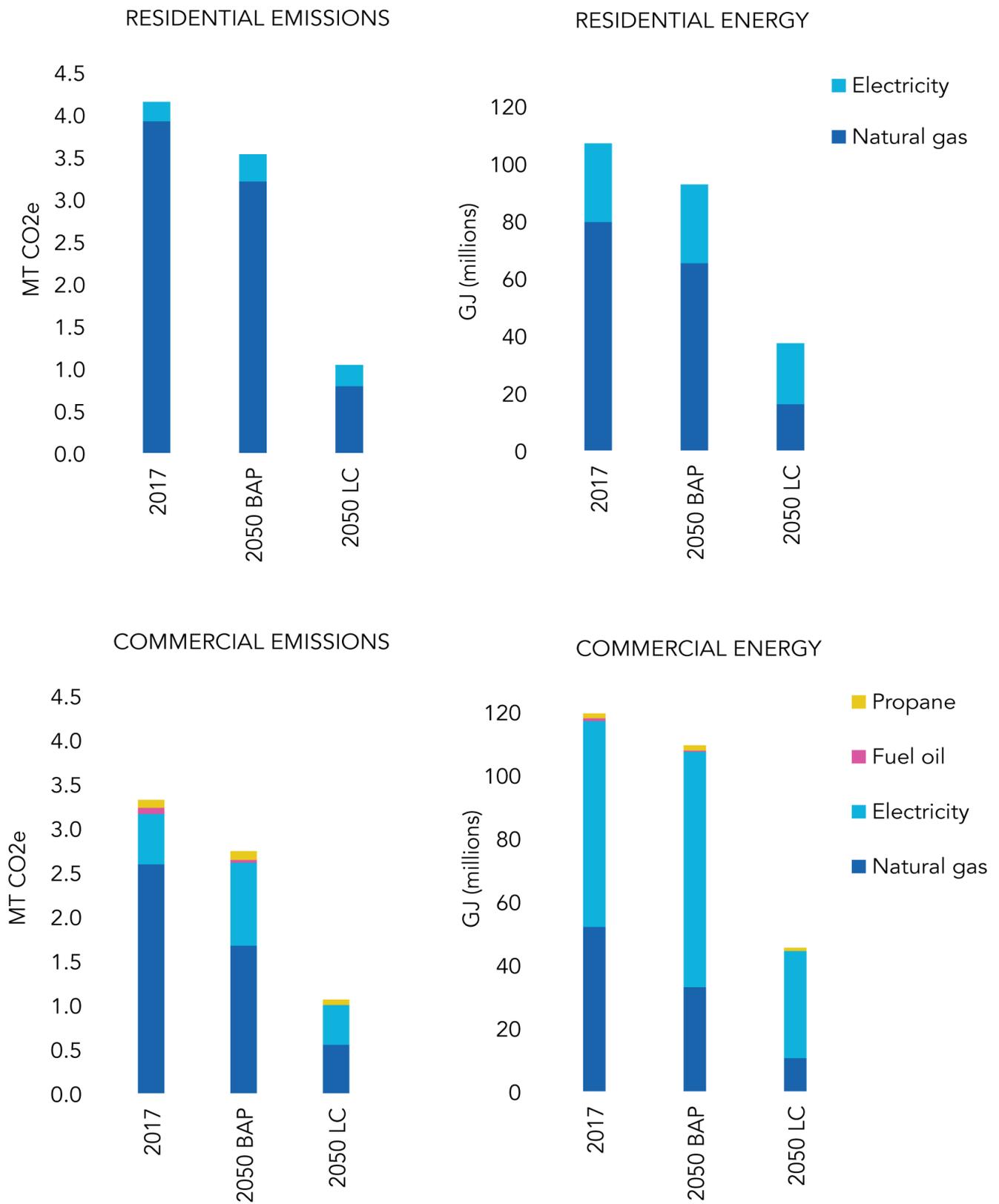
Figure 11. Residential and commercial energy and emissions by fuel.

*LCS Modelling Assumption: All buildings are systematically recommissioned to ensure that the building systems are operating as intended.*

In addition to retrofits, commercial buildings are regularly recommissioned, a process of examining how a building's operating and maintenance systems are functioning and optimising these systems after a building has been fully operational for a period of time.

*Observations*

Total energy consumption in buildings decreases to 2050 in the LCS, with residential buildings consuming approximately 65% less, and commercial buildings 62% less, compared with 2017. Figure 11 shows that emissions reductions in residential buildings result predominantly from decreases in energy consumption; the share of natural gas relative to electricity remains fairly constant to 2050.

The emissions reduction in commercial buildings is more significant, and results from both decreases in consumption, and a larger shift to electricity away from natural gas; in 2017, approximately 44% of commercial building energy demand is met by natural gas, compared with 23% in 2050 in the LCS.

Figure 12 to Figure 15 show energy intensity (EUI) by zone for the BAP and LCS in 2050 respectively. The maps show that there is a general decrease in building energy use carbon intensities geographically across the city.

BUILDING ENERGY INTENSITY FOR THE CITY OF TORONTO BUSINESS AS PLANNED SCENARIO, 2050

Legend

Stationary energy intensity (MJ/m2)

- 0 - 600
- 600 - 1,200
- 1,200 - 1,500
- 1,500 - 3,000
- >3,000
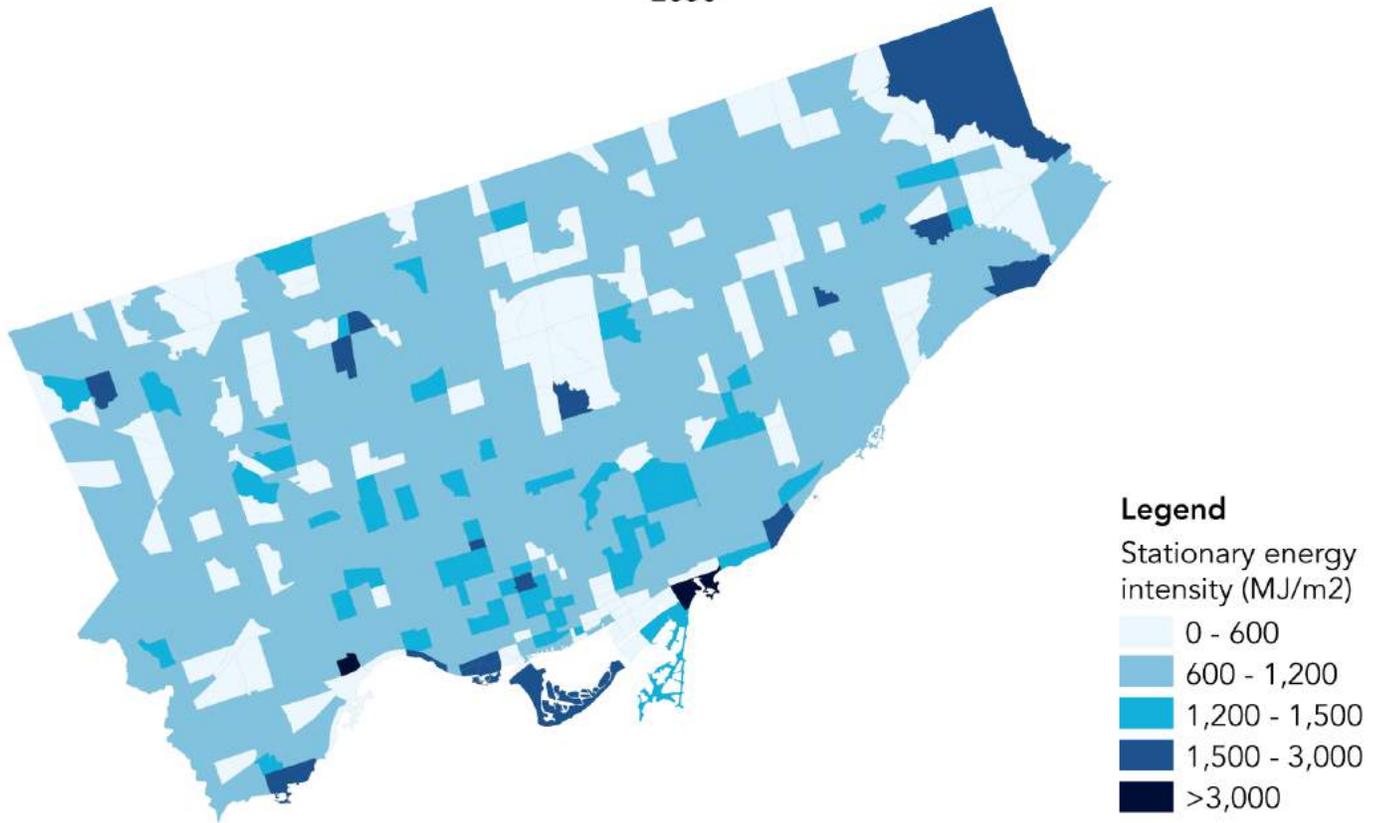
*Figure 12. Building energy intensity (MJ/m2 by zone), BAP 2050.*

BUILDING ENERGY INTENSITY FOR THE CITY OF TORONTO LOW CARBON SCENARIO, 2050

Legend

stationary energy intensity (MJ/m2)

- 0 - 300
- 300 - 600
- 600 - 900
- 900 - 1,200
- 1,200 - 1,500
- 1,500 - 3,000
- >3,000
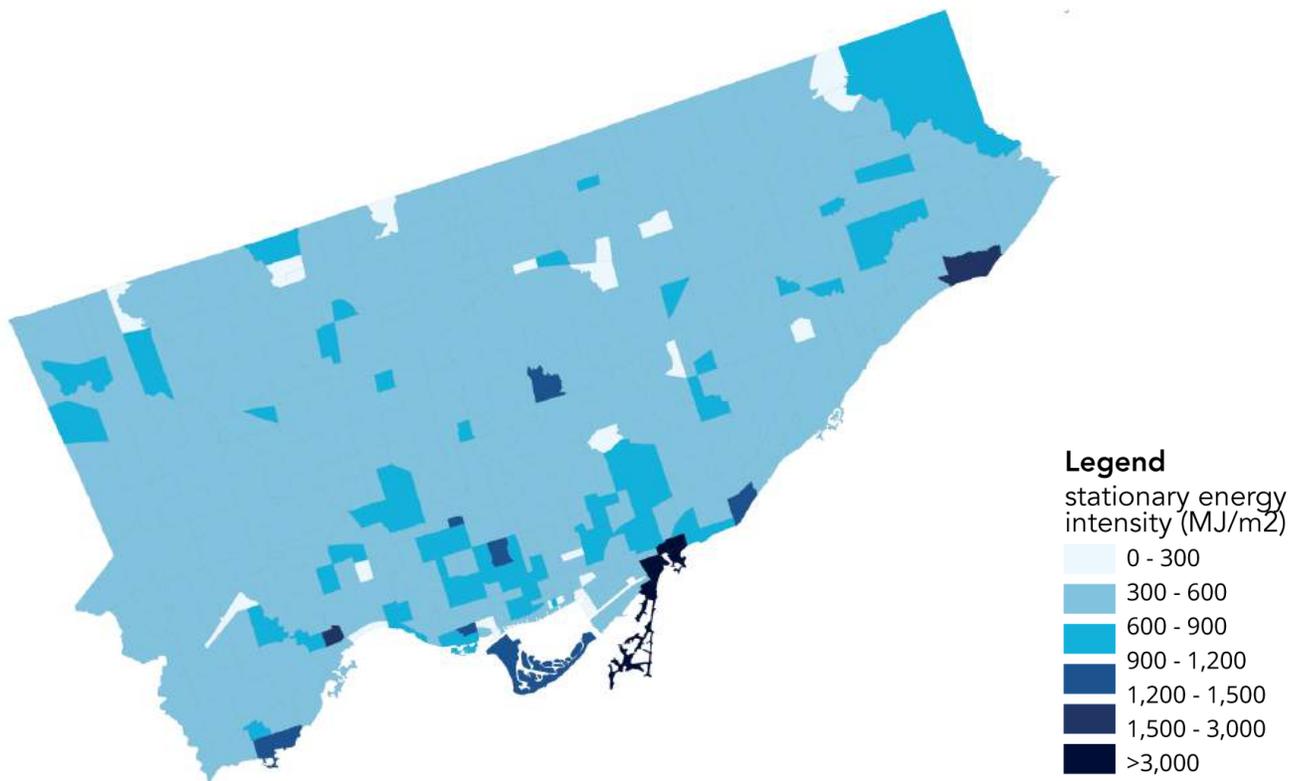
*Figure 13. Building energy intensity (MJ/m2), Low Carbon 2050.*

BUILDING EMISSIONS FOR THE CITY OF TORONTO BUSINESS AS PLANNED SCENARIO, 2050

Legend

Stationary emissions (tCO2e/yr)

0 - 10,000
10,000 - 20,000
20,000 - 30,000
30,000 - 40,000
40,000 - 50,000
≥50,000

*Figure 14. Building emissions (tCO2e/yr), BAP 2050.*

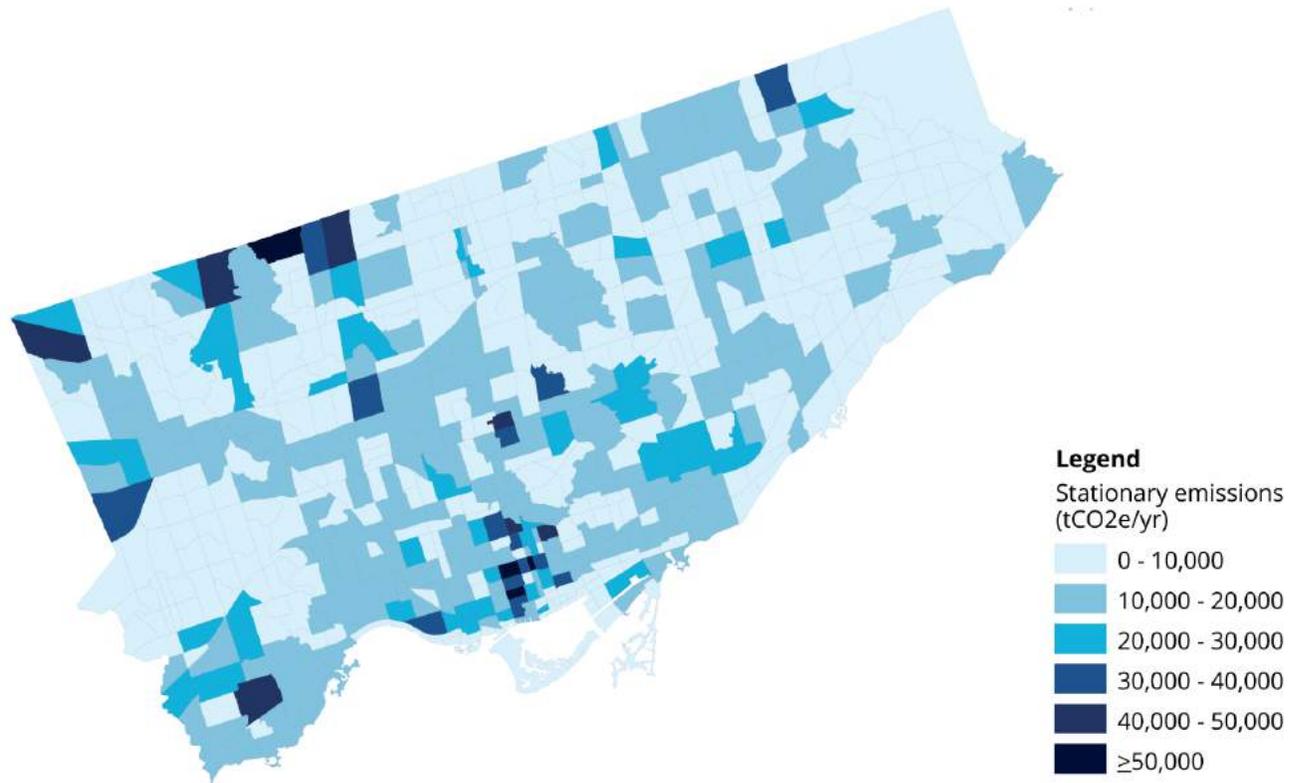BUILDING EMISSIONS FOR THE CITY OF TORONTO LOW CARBON SCENARIO, 2050

Legend

stationary emissions (tCO2e/yr)

0 - 10,000
10,000 - 20,000
20,000 - 30,000
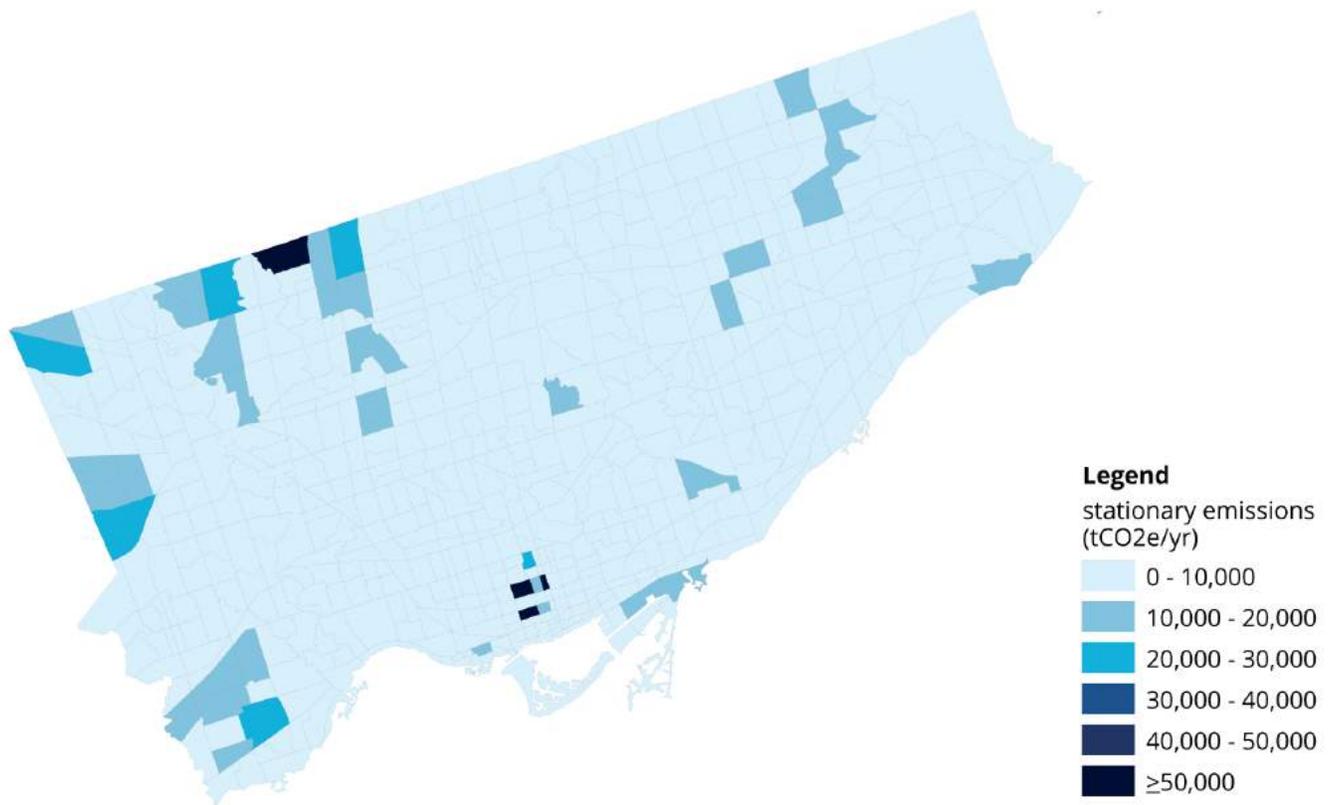30,000 - 40,000
40,000 - 50,000
≥50,000

*Figure 15. Building emissions (tCO2e/yr), Low Carbon 2050.*

There are two key strategies for buildings; firstly, retrofit the existing or pre-2016 building stock and secondly increase the efficiency of the post-2016 buildings stock to near net zero GHG emissions. Both of these strategies build on existing efforts within the City, which need to be scaled up. The retrofit efforts will target over 400 pre-2016 buildings each year initially, and scales back in the annual number of building retrofit incrementally towards 2050. In parallel, the TGS will incrementally increase the performance of new construction out until 2030. The overall result of these measures is a total building stock in the LCS that uses 40% less energy in 2050 than in 2011, or just under half as much energy as the same building stock in 2050 in the BAP.

## 4.3   Energy system

*LCS Modelling Assumption:  Buildings are renewable energy generators.*

Photovoltaic panels are installed on nearly all rooftops by 2050, using a net metering approach. For new construction, the installation scales up so that by 2050, every new building incorporates a PV system that provides on average 25% of the building's electrical load.  In a separate but similar action, PV installs increase to 75% of all pre-2016 buildings by 2050. Total potential rooftop area available for PV installation was estimated from building counts and their footprint areas for all residential and non-residential buildings.  While some roofs, particularly pitched roofs, are larger than their footprint areas, a 1:1 ratio between footprint and roof area was assumed, since overhangs are often not used due to their being less structurally stable to access for installation and maintenance.  Eight percent (8%) of residential roofs and 63% of commercial roofs were assumed to be flat, and the remainder assumed pitched. Pitched footprint areas were multiplied by a factor of 1.051, assuming an average 18 degree slope angle.  Total roof area usable for PV installations for flat and pitched roofs was then determined assuming 35% shading for flat roofs and 41.5% shading on pitched roofs, caused by features such as chimneys, ventilation equipment, and building orientation. Solar PV and heating systems are also installed on facades.

## SOLAR ENERGY COSTS AND DEPLOYMENT IN THE UNITED STATES
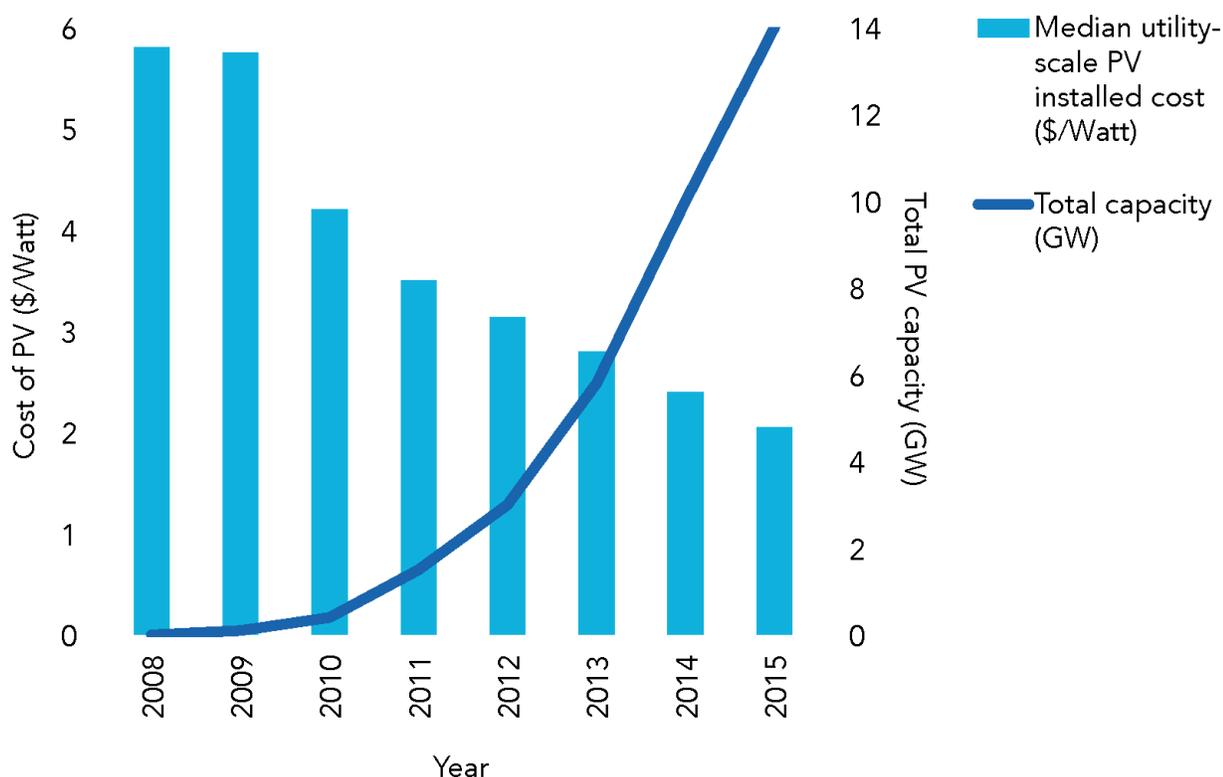


Source: U.S. Department of Energy (2016). Note: Costs in real 2015 dollars.

*Figure 16. Costs of solar PV*

### LCS Modelling Assumption: Areas of the City are heated and cooled with renewable district energy

District energy was modelled to supply areas within the city that exceed a heat density threshold of 140 MJ/m2, incrementally increasing until full coverage of the area indicated in Table 4 is served by district energy.[46]  A total of nearly 110 million m2 is connected to district energy, out of total floor space in the city of 300 million m2. District energy was applied in the modelling after retrofitting and the application of TGS in order to right-size the system capacity.

---

46    A threshold of 140 MJ/m2 was used as informed by analysis in the EU that ranges from 100-200 MJ/m2. Fourth generation district energy systems are anticipated to have density thresholds below 100 MJ/m2, so 140 is conservative. See the following for more details: AEA, ANKO, ARPA, BSERC, CRES, & EKODOMA. (2016). Six regional maps of the RES H/C supply and demand potential. Retrieved from http://www.res-hc-spread.eu/wp-content/uploads/2015/08/Six-Regional-Maps-of-the-R

*Table 4. Floor space incorporated within the district energy system.*

| | FLOORSPACE SERVED (SQM) | | DWELLING UNITS | BUILDINGS |
| | Residential | Non-Residential | Residential | Non-Residential |
|---|---|---|---|---|
| Space & water heating | 56,447,992 | 53,420,776 | 631,360 | 8,734 |
| Space cooling | | 35,733,336 | | 3,189 |

ZONES THAT MEET OR EXCEED THE 140 MJ/m2 THRESHOLD FOR DISTRICT ENERGY IN THE CITY OF TORONTO LOW CARBON SCENARIO, 2050



Legend
MJ/m2 land area for space and water heating

0 - 140
140 - 200 ← Threshold for
200 - 500    district energy
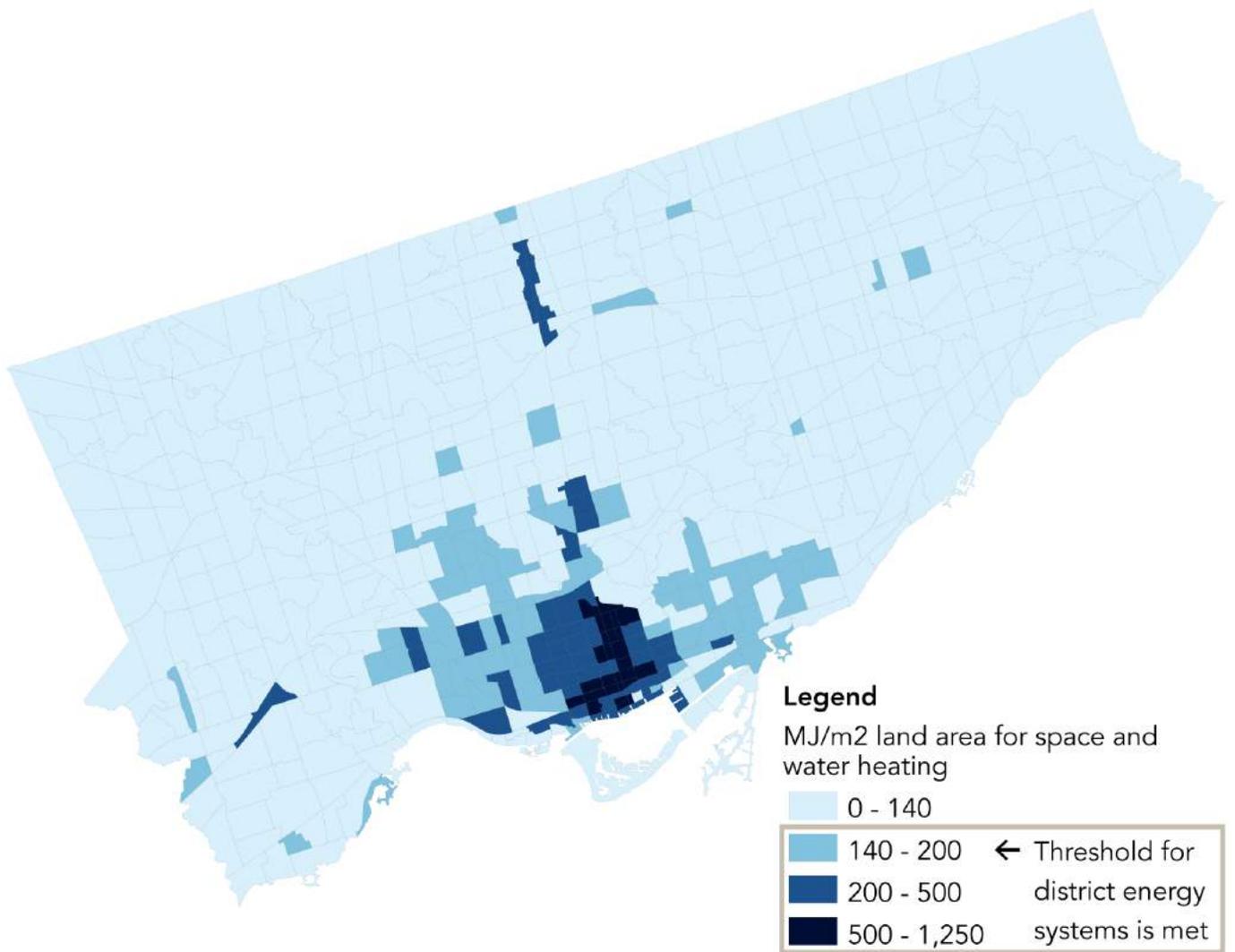500 - 1,250   systems is met

*Figure 17. Zones identified in the modelling that meet or exceed the 140 MJ/m² threshold for district energy in the 2050 LCS.*

All new generation for district energy relies on zero carbon renewable sources, including expanded deep water lake cooling, use of renewable natural gas, industrial waste heat, geothermal (ground source heat pumps), and facade combined heat and power.[47]

In aggregate the energy supply for the district energy system is as follows:

- biogas (renewable natural gas)- 41%

- geothermal- 21%

- industrial waste heat- 17%

- deepwater cooling-13%; and

- facade combined heat and power solar- 8%.

### LCS Modelling Assumption: Natural gas heating is replaced with air source heat pumps.

Fuel switching from natural gas to electricity relies on the introduction of cleaner fuel sources for space heating and water heating, targeting in particular the building stock for which district energy is not available. Heat pumps are used to efficiently harvest heat, and are a preferred option for fuel switching away from natural gas to electricity. In the LCS, 50% of the residential stock and 60% of the commercial stock have air source heat pumps by 2050.  The projected decline in natural gas consumption for space heating is the result of both increased efficiencies in buildings, and fuel switching space heating away from natural gas to heat pumps and district energy. By 2030, 2040 and 2050 natural gas consumption for space heating in residential and non-residential buildings declines by 60%, 84% and 16% respectively, all over 2011 levels.

### LCS Modelling Assumption: Energy storage is dispersed throughout the city.

Energy storage enables time shifting between renewable energy generation and demand for power, increasing the percentage of power that is generated by renewables that can be used, and decreasing the reliance on fossil fuel-based peaking plants.[48]  The City of New York has committed to 100 MW of energy storage by 2020.[49]  For Toronto, a target of 100 MW was modelled

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47    Façade combined heat and power is a hybrid solar thermal and solar PV system with enhanced energy collection, because solar PV cells become less efficient as they become hotter.

48    New York Battery and Energy Storage Technology Consortium. (2016). Energy storage roadmap for New York's electric grid. Retrieved from https://www.ny-best.org/sites/default/files/type-page/39090/attachments/NY-BEST%20Roadmap_2016_Appendices_finalpages.pdf

49    Mayor's Office of Sustainability. (n.d.). New York City's Roadmap to 80X50. 2016. Retrieved from http://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/New%20York%20City%27s%20Roadmap%20to%2080%20x%2050_20160926_FOR%20WEB.pdf

for 2025, scaling up to 1000 MW by 2050, as increasing renewable capacity comes online from other actions.

### LCS Modelling Assumption: Industrial efficiencies continue to improve.

A general action was identified for the industrial sector which builds on the results of the Natural Gas Conservation Potential study for Ontario.[50] The study identified technical potential reductions in natural gas consumption of 24% by 2030; this was scaled up to 40% by 2050, and was applied to natural gas consumption associated with process heating.

### Observations

District energy on the scale contemplated in the LCS will require careful consideration of timing in terms of connecting to buildings when boilers are being replaced and in terms of laying pipe when other city infrastructure is being installed in order to minimize costs. The fuel source for district energy is context specific and will require additional analysis in order to capture and utilize sources of waste heat and to utilize ground-source heat pumps in locations where there is space, for example. For areas not suitable for district energy connection, heat pumps are installed to fuel switch from natural gas to electricity for space heating. Finally, the decreased cost of solar PV is an opportunity to decentralize electricity generation using renewable energy on roofs across the city.

## 4.4 Transportation

### LCS Modelling Assumption: The City helps people plan their transportation options.

The City of Toronto already delivers a transportation demand management program called Smart Commute. This action expands this program by systematically targeting areas of the city with high VKT and providing personalized transportation planning as a mechanism to influence the mode choices of citizens both for personal and commuting travel.[51] While personal transportation planning could be widely applied in the city, areas with high VKT were targeted in order to leverage the impact of additional transit services introduced in these areas. The program focused on personal travel planning but also included travel awareness campaigns, promoting walking and cycling, public transport marketing, and workplace/school travel plans.

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50    ICF International. (2016). Natural gas conservation potential study. Ontario Energy Board. Retrieved from http://www.
      ontarioenergyboard.ca/oeb/_Documents/EB-2015-0117/ICF_Report_Gas_Conservation_Potential_Study.pdf

51    Sloman, L., Cairns, S., Newson, C., Anable, J., Pridmore, A., & Goodwin, P. (2010). The effects of Smarter Choice programmes
      in the Sustainable Travel Towns: full report. Retrieved January 5, 2017, from https://www.gov.uk/government/publications/the-
      effects-of-smarter-choice-programmes-in-the-sustainable-travel-towns-full-report

*LCS Modelling Assumption: Neighbourhoods become car free.*

Car free areas result in the vehicular mode share declining to zero to and from identified zones. A City report in 2003 identified potential areas for car free zones;[52] this was updated with an additional area in Waterfront Toronto. The car free zones are incrementally implemented whereby auto mode share for these zones are ramped down linearly from 2017 to 2050. Figure 18 illustrates the car free zones.
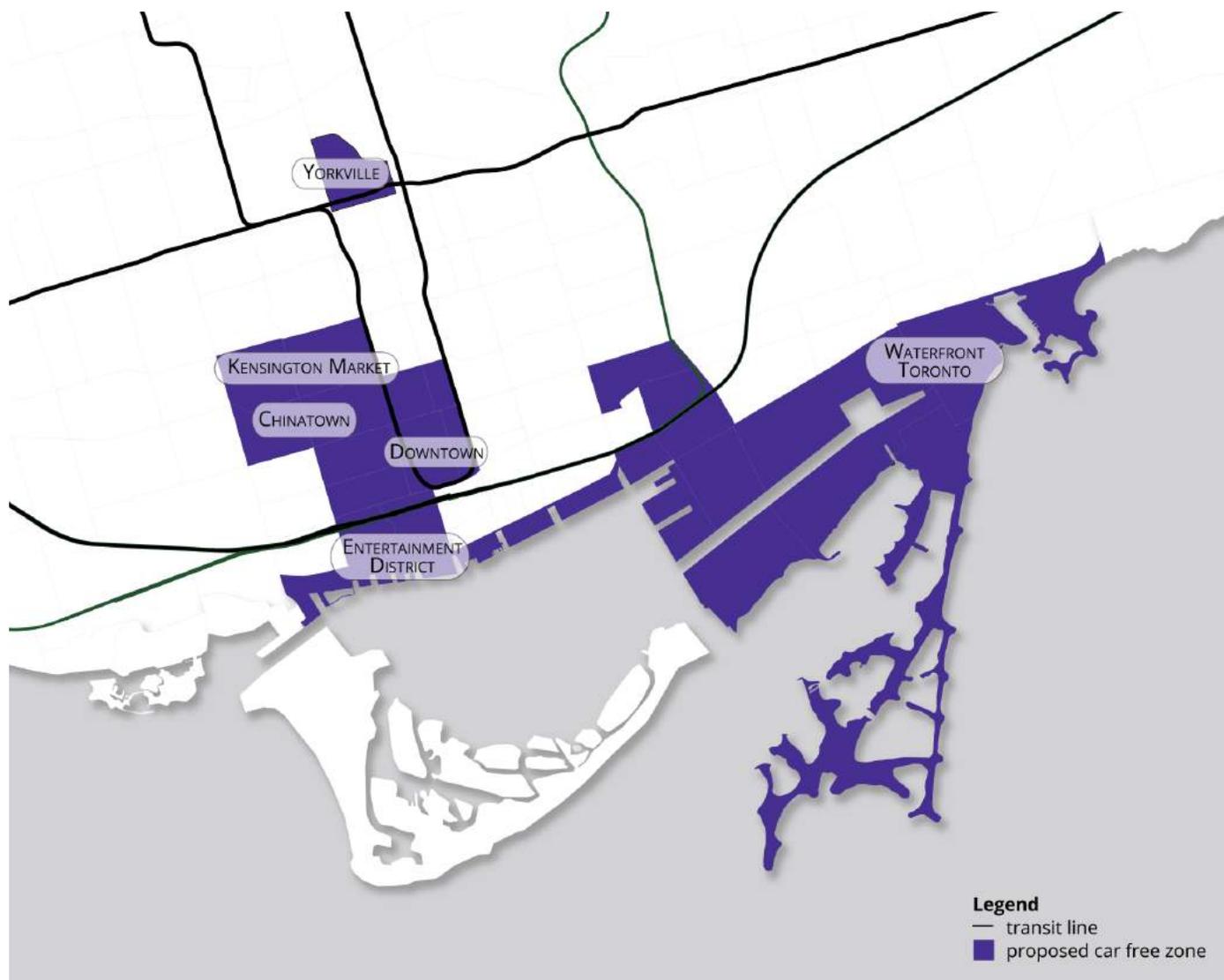


*Figure 18. Car free zones.*

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52    City of Toronto. (2003). Car free day and car free pedestrian zones (Staff report). Retrieved from http://www.toronto.ca/legdocs/2003/age

*LCS Modelling Assumption:  A four-day work week is implemented by many businesses and organizations.*

Half of the employees in the city work four days per week, with the effect of avoiding trips, and reducing VKT for work trips by 15%. The 15% reflects a minor rebound effect; even if there is a shift to a four-day work week, some trips will inevitably occur on the fifth day as employees who are not working take additional leisure trips or other trips for meetings.

*LCS Modelling Assumption:  Most short trips are by walking or cycling.*

The majority of trips within the City of Toronto are less than 10km in length, creating a significant opportunity for mode shifting to walking and cycling. Figure 19 and Figure 20 illustrate the shift in mode for shorter trips in 2050, a shift that can result from measures such as supporting those who already walk and cycle to increase their active trips and building a culture of walking and cycling across the population through education, investments in walking and cycling infrastructure and behavior change mechanisms and incentives. Each coloured bar represents the number of trips. The LCS in 2050 includes a significant increase in short trips by bicycle (pink bars) in comparison with the BAP in 2050, as a result of 75% of trips between 1 and 5 km shifting to cycling in the modelling (Figure 20). An increase in walking trips is also evident in the blue bar, particularly for very short trips. The walking and cycling targets were derived exogenously from CityInSight.[53]  The decline in vehicle trips, particular for shorter trips, is apparent in the decreased green bar, particularly for those of a distance of 5 km or less. By 2050, the cycling mode share climbs to 28% of the total internal trips and 19% of the combined internal and external trips, below the current cycling mode share of European cities such as Amsterdam (32%)[54] and Copenhagen (30%).[55]

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53    The targets were identified based on an analysis in the following report: Mitra, R., Smith Lea, N., Cantello, I., & Hanson, G. (2016). Cycling behaviour and potential in the greater Toronto and Hamilton area. Retrieved from http://transformlab.ryerson.ca/wp-content/uploads/2016/10/Cycling-potential-in-GTHA-final-report-2016.pdf.  This report identified 31% of cycling trips in the Greater Toronto area that can be considered potentially cyclable. In CityInSight analysis, 28% were identified, slightly less than the total in the report.

54    City of Amsterdam. (2017). Cycling facts and figures. Retrieved April 14, 2017, from http://www.iamsterdam.com/en/media-centre/city-hall/dossier-cycling/cycling-facts-and-figures

55    This number represents the combined internal and external trips: City of Copenhagen. (2015). Copenhagen city of cyclists- the bicycle account 2014.

## PERSON TRIPS BY MODE AND TRIP DISTANCE (TRIPS/YEAR) - BAP 2050
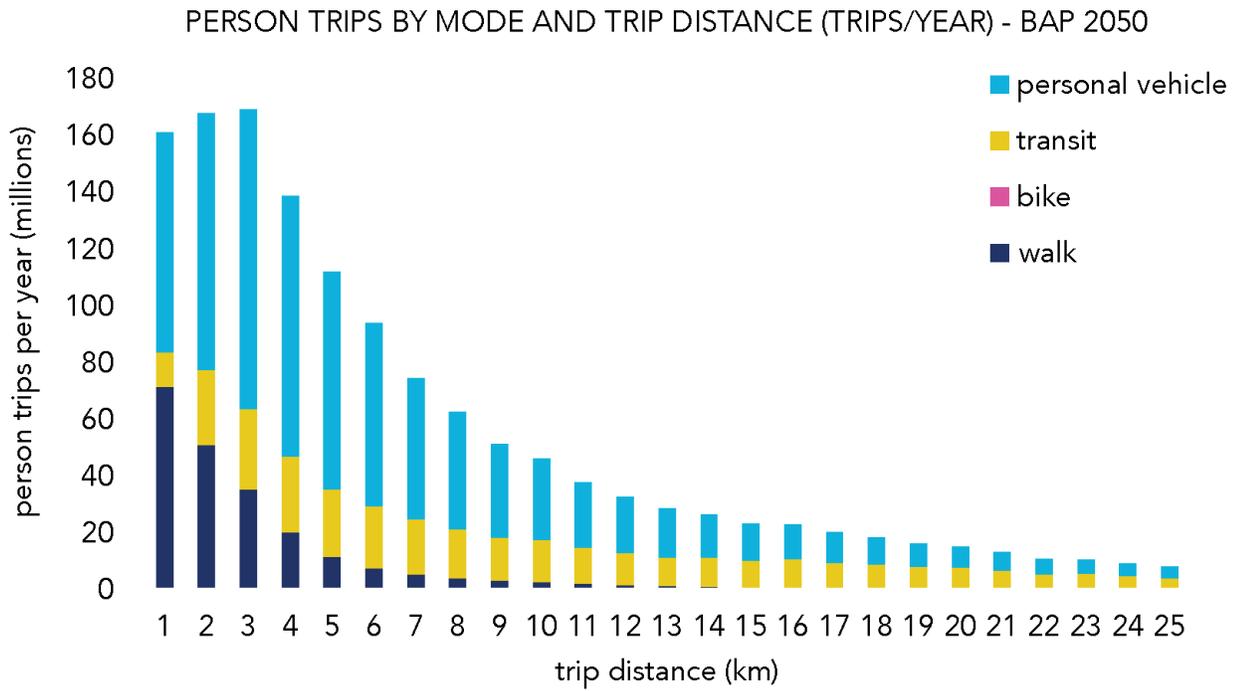


*Figure 19. Person trips by mode and distance, BAP 2050.*[56]

## PERSON TRIPS BY MODE AND TRIP DISTANCE (TRIPS/YEAR) - LC 2050
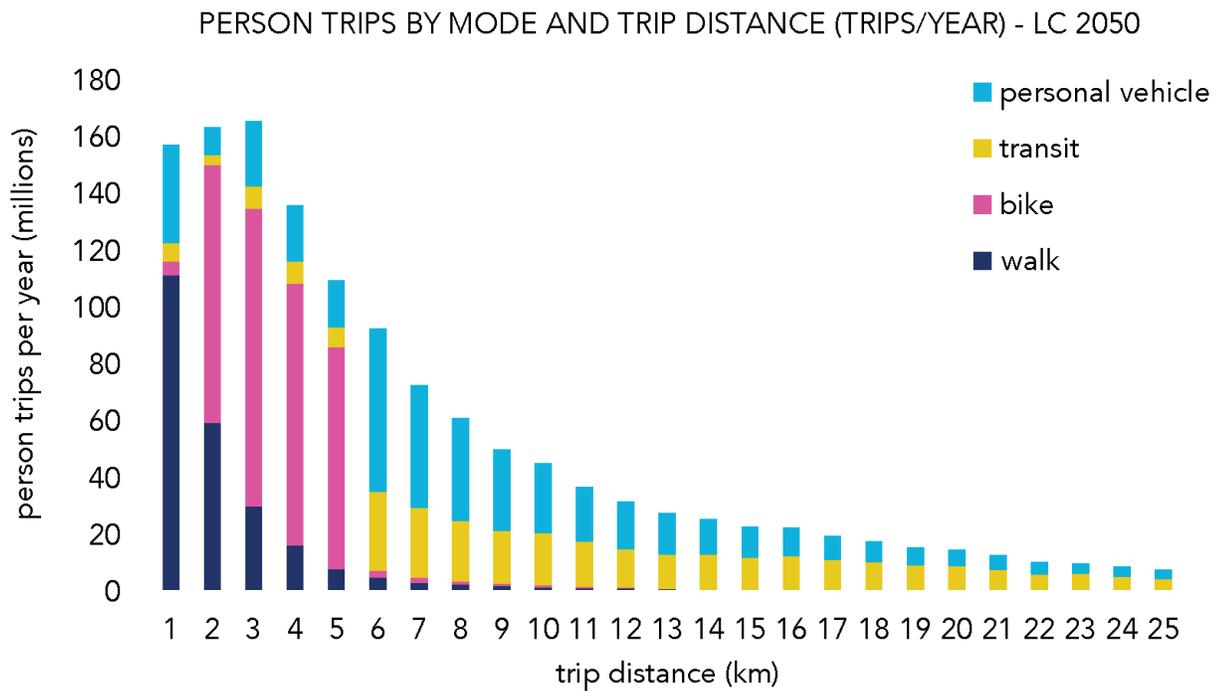


*Figure 20. Person trips by mode and distance, Low Carbon 2050.*

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56   Note that the City does not split out walking and cycling trips in its transportation modelling so walking and cycling trips were classified as active transportation.

*LCS Modelling Assumption:  Frequent transit services all areas of the city.*

By 2031 in the BAP, the City's transit system was assumed to include the Scarborough Subway Extension, GO's Regional Express Rail, Eglinton Crosstown Rail Transit, Finch West Rail Transit, Sheppard East Rail Transit and Toronto-York Spadina Subway Extension. No further expansion in the transit system was assumed between 2031 and 2050. The Toronto Transit Commission subway cars and streetcars were assumed to continue to run on electricity while buses are assumed to be diesel without any improvements in efficiency. The BAP assumes that 86% of GO train VKT will be fueled by electricity beginning in 2031, which is held constant until 2050.[57]

In the LCS, the transit system is built out, as illustrated in Figure 21, including 24 additional rapid transit lines, Regional Express Rail (RER+) including stops at Richmond Hill and Milton (CP freight line), and the development of an express bus network across the city.

---

57    The 86% assumption was based on a breakdown between diesel and electric rail provided by the City of Toronto.

**Rapid Transit**
- — TTC Existing
- — Funded/Under Construction
- — Future Transit Projects
- — Alignment To Be Determined
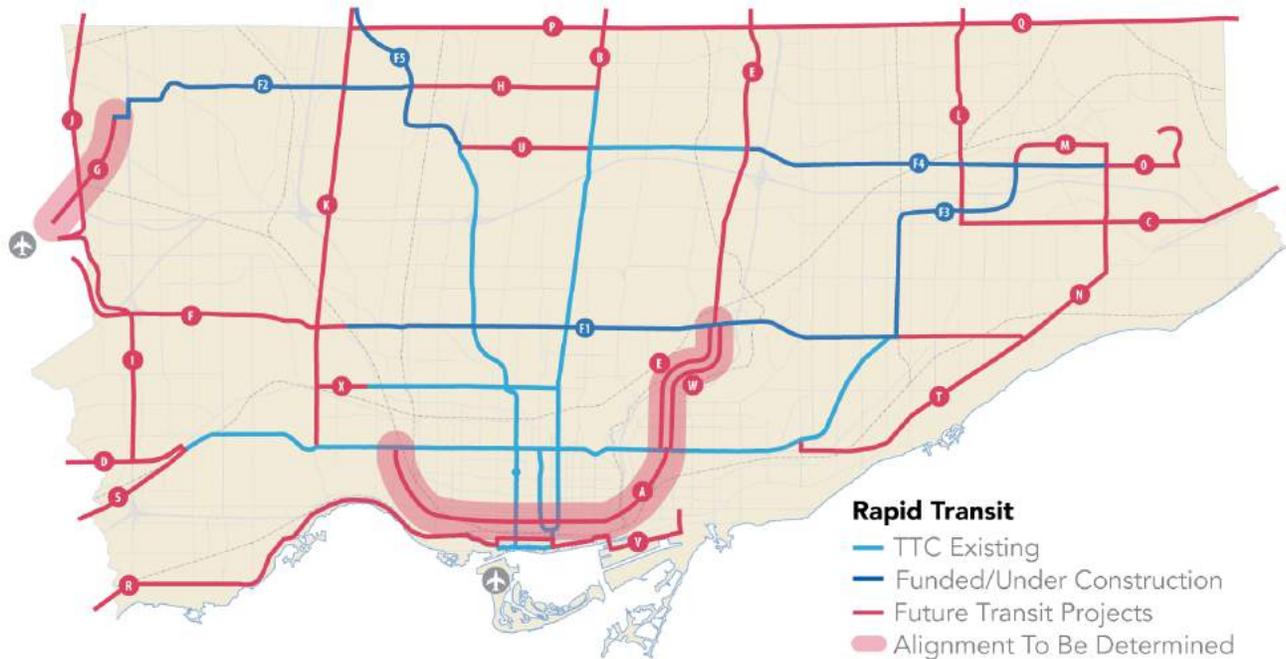
**Currently Funded Rapid Transit Projects**
- ⓕ¹ Eglinton Crosstown LRT
- ⓕ² Finch West LRT
- ⓕ³ Scarborough RT Replacement & Extension
- ⓕ⁴ Sheppard East LRT
- ⓕ⁵ Toronto-York Spadina Subway Extension (TYSSE)

**Unfunded Future Rapid Transit Projects**
- Ⓐ Relief Line (subway)
- Ⓑ Yonge North Subway Extension
- Ⓒ Durham-Scarborough BRT
- Ⓓ Dundas Street BRT
- Ⓔ Don Mills LRT
- Ⓕ Eglinton LRT West Extension
- Ⓖ Finch West LRT West Extension
- Ⓗ Finch West LRT East Extension
- Ⓘ Highway 427 Airport BRT South
- Ⓙ Highway 427 Airport BRT North
- Ⓚ Jane LRT
- Ⓛ McCowan Road BRT

- Ⓜ Scarborough RT/LRT Extension
- Ⓝ Scarborough Malvern LRT
- Ⓞ Sheppard East LRT Extension
- Ⓟ Steeles LRT/BRT West
- Ⓠ Steeles LRT/BRT East
- Ⓡ Waterfront West LRT
- Ⓢ Bloor-Danforth Subway West Extension
- Ⓣ Kingston Road BRT
- Ⓤ Sheppard West Corridor
- Ⓥ Waterfront East LRT
- Ⓦ Relief Line East Extension (subway)
- Ⓧ St. Clair Streetcar/LRT Extension

*Figure 21. Potential Toronto rapid transit system.*[58]

The frequency of all transit was increased, including subways at 110 seconds, LRT at 120 seconds, BRT at 90 seconds, as well as doubled off-peak frequency for the Regional Express Rail. A 20% increase in speed for BRT and LRT was also assumed and fares were integrated amongst different transit modes. A carbon tax was applied to private vehicle use, although its effect was minimal at $0.01/km by 2022 and $0.014/km by 2050.[59] Finally, a congestion charge cordon was introduced for the Toronto Central Area,[60] i.e., Bathurst Street to the west, CP Rail North Toronto Subdivision to the

58    City of Toronto. (2013). Feeling congested- Toronto talks transportation- Phase 2 toolkit. Retrieved from http://www.feelingcongested.ca/assets/FeelingCongestedToolkit-Web.pdf

59    Calculated based on a carbon tax of $50/tonne in 2022 and $120/tonne in 2050.

60    KPMG. (2016). City of Toronto revenue options study. Retrieved from http://www.toronto.ca/legdocs/mmis/2016/ex/bgrd/backgroundfile-94513.pdf

north, Bayview Avenue/Don River to the east and Lake Ontario to the south. The cordon charge of $20[61] was applied between 6:00 am and 10:00 am on weekdays. This combination of transit actions, described as complete by 2050, was incrementally implemented between 2017 and 2050.

While comprehensive, the bundle of actions had a small impact on VKT and resulted in a decline of less than 2% in vehicular mode share. One of the reasons for the disproportionately small impact is that areas in Toronto which are densely populated already have high rates of transit use in the BAP. In the LCS additional transit infrastructure is targeting lower density areas, which are more difficult to service with transit as dwellings and employment are spatially distributed. Figure 22 is a three dimensional representation of population and employment density in the city; the new transit added in the LCS (the unfunded lines in Figure 21) focuses on areas that do not have high population and employment, and significant mode shifts are more challenging to achieve.
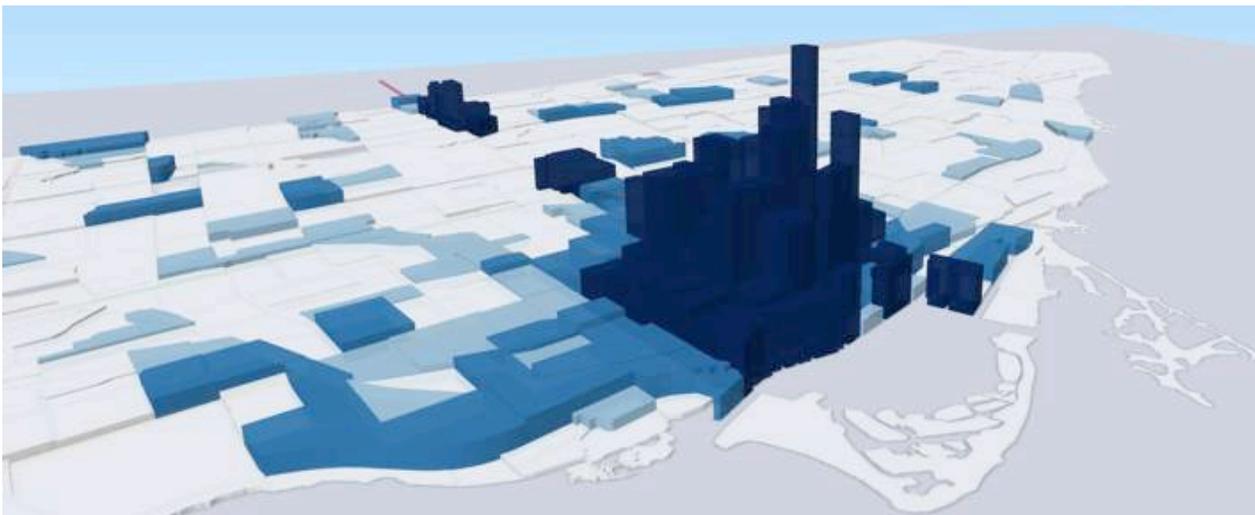


*Figure 22. A three dimensional representation of the density of population and employment in 2050.*

The transit actions were primarily focused within the city boundaries and therefore did not have a meaningful influence on inbound and outbound traffic, as illustrated in Figure 30. Another consideration is that the City's transportation model, which was used to evaluate the transit actions, is calibrated to existing transportation preferences, and attitudes towards transit could evolve in the LCS.

---

61    In order to test the impact of a cordon charge, a significant fee, $20, was tested; slightly more than the fee of 11.50 pounds (CAN$ 18.85) used in the UK. See: https://tfl.gov.uk/modes/driving/congestion-charge

## LCS Modelling Assumption: The entire personal vehicle fleet is electrified by 2050.

In terms of the "improve" aspect of the ASI (avoid, shift, improve) approach, the primary intervention is to electrify the vehicle fleet. The action for the transit fleet includes 100% electrification of light rail, subway, streetcar and buses by 2040. For private vehicles, the action assumes all new vehicles in Ontario after 2030 will be electric; an action which is consistent with commitments announced by Germany[62] and Norway,[63] but exceeds the current projections in Ontario, as illustrated in Figure 23. Because of the durability of the vehicle stock, even if all new vehicles are electric by 2030, it will take until 2050 before all vehicles are electric, a key component in achieving the 2050 GHG reduction target in the LCS. The blue line illustrates the aggressiveness of the electric vehicle (EV) adoption rate for new vehicles in the LCS versus the other curves which are in line with provincial projections, implying that additional efforts will be required to advance the uptake of EVs.



SCENARIOS FOR ELECTRIC VEHICLE ADOPTION IN THE CITY OF TORONTO, 2010 - 2064

Year that EVs reach 100% of new LDVs
- LCS (2030)
- 2048
- 2050
- 2052
- 2054

Y-axis: Share of light duty vehicle stock that are electric
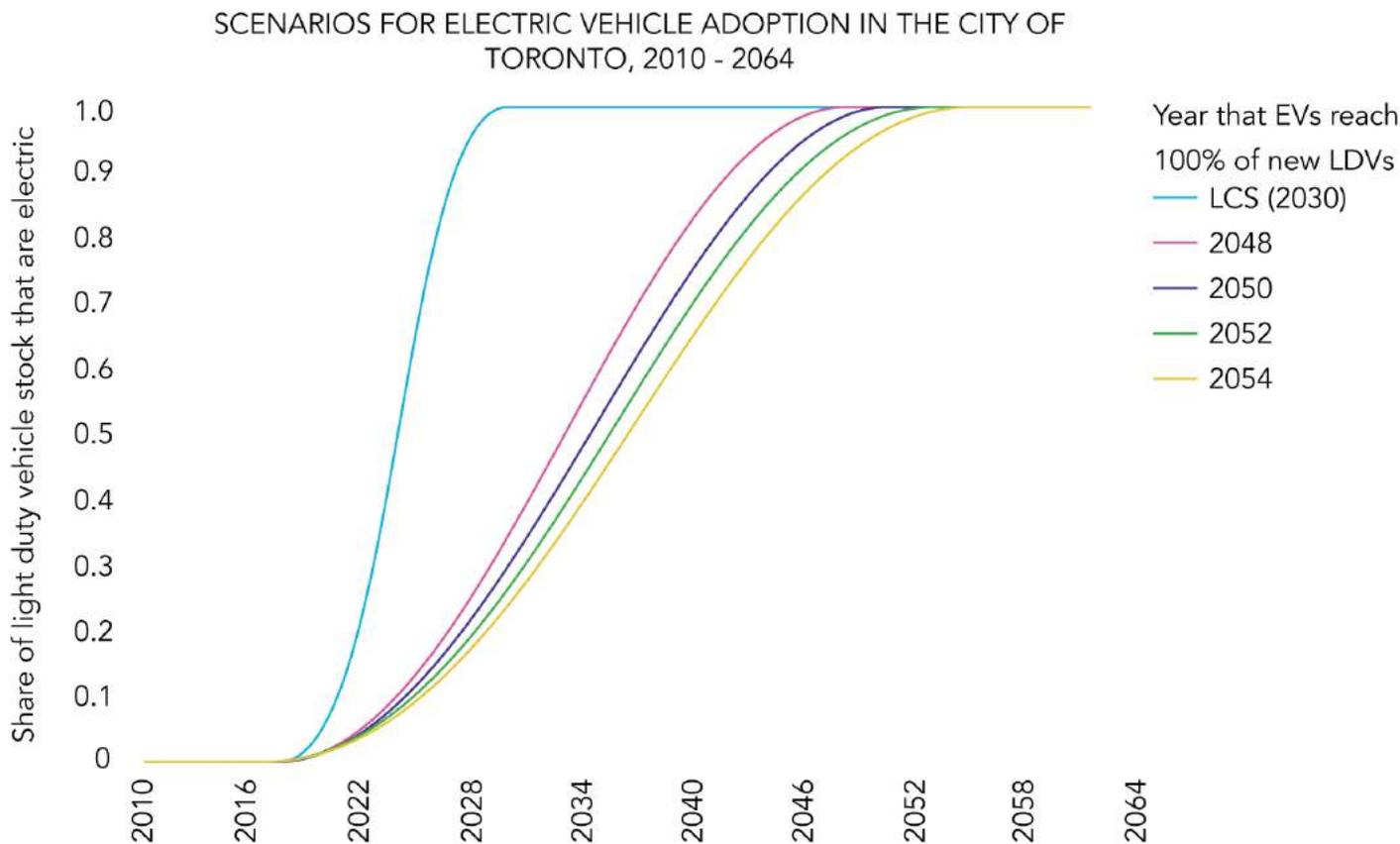
*Figure 23. Electric vehicle adoption rate*

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62    Schmitt, B. (2016). Germany's Bundesrat resolves end of internal combustion engine. Retrieved January 3, 2017, from http://www.forbes.com/sites/bertelschmitt/2016/10/08/germanys-bundesrat-resolves-end-of-internal-combustion-engine/#b1c666a31d95

63    Staufenberg, J. (2016). Norway to "completely ban petrol powered cars by 2025." Retrieved January 3, 2017, from http://www.independent.co.uk/environment/climate-change/norway-to-ban-the-sale-of-all-fossil-fuel-based-cars-by-2025-and-replace-with-electric-vehicles-a7065616.html

Figure 24 30 describes the S curve, a common trajectory for the uptake of new technologies,[64] which is used in CityInSight as a trajectory for the introduction of EVs. The rate of adoption increases significantly after the early adoption period, creating a cascading effect as the technology becomes increasingly accepted.



TECHNOLOGY ADOPTION AND MARKET SHARE
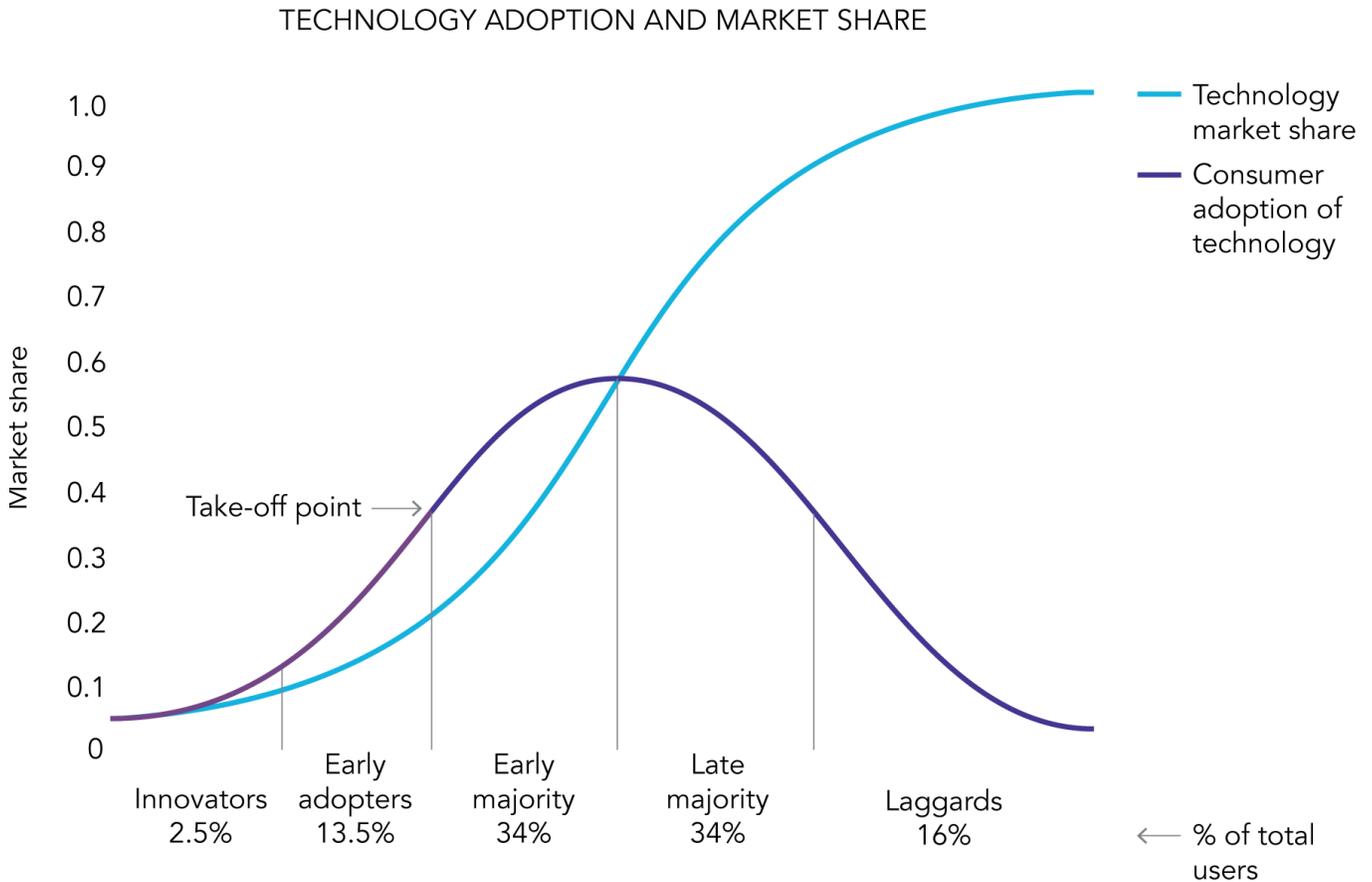
Figure 24. The S curve

*LCS Modelling Assumption: The City's fleet of vehicles is electrified more quickly than the personal fleet.*

Electric vehicles are introduced into the City of Toronto's corporate fleet beginning in 2020 and by 2042, the corporate fleet is 100% electric, excluding transit, as internal combustion engine vehicles are replaced generally at the end of their life. This type of intervention by the City can provide additional stimulation for the EV industry.[65]

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64    Rogers, Everett. (2003). The diffusion of innovations. New York: The Free Press.z

65    Dovey, R. (2017, January 12). West coast mayors want to buy electric vehicles in bulk. Next City. Retrieved from https://nextcity.org/daily/entry/mayors-electric-vehicle-city-fleets

## LCS Modelling Assumption: Autonomous vehicles increase energy consumption.

Autonomous vehicles (AVs) are introduced in the period between 2020 and 2050, resulting in increase in VKT over personal vehicles and consequently an increase in GHG emissions. This increase is because as more of the population will have access to vehicles, VKT are assumed to increase, which in turn leads to an increase in electricity consumption as AVs are assumed to be electric in the LCS. Electricity still has some associated emissions in 2050 and therefore emissions associated with AVs increase. AVs are assumed to follow the same rate of adoption as EVs.

## LCS Modelling Assumption: Freight transportation is more efficient.

The primary intervention in the freight sector was to shift to low or zero carbon vehicles for freight transportation. A report produced by the Sustainable Transportation Energy Pathways Project describes various scenarios for heavy duty trucks.[66]  The action assumed that 40% of heavy truck sales are zero emissions vehicles by 2030 and 20% more are near zero emission vehicles. By 2040, all conventional vehicle sales are phased out and only fuel cell, electric and plug-in hybrid trucks are sold. Additional petroleum fuels are eliminated for all modes, and by 2050 all liquid fuels are renewable.

While the bulk transportation of goods is relatively efficient, the last mile of delivery involves a large of number of end destinations, resulting in a disproportionate use of energy. Two strategies were applied to reduce the impact of the last mile of delivery including relaxed delivery times[67] and collection delivery points. Collection delivery points are locations, attended or unattended, such as post offices, warehouse areas or other staffed sites where couriers can deliver goods when recipients are not at home.

### Observations

The approach of avoid, shift and improve provides a hierarchy to the implementation of actions in the transportation sector. There are many opportunities to shift short trips from vehicles to walking and cycling.

Increased transit, beyond what is included in the BAP, does not result in a major reduction in VKT, because of a variety of factors including the difficulty of influencing external trips and the existing high transit mode share in dense areas of the city. Like land-use, transit investments can also generate positive feedback cycles. New rapid transit lines are attractors for dense, mixed-use

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66    Fulton, L., Miller, M. (n.d.). Strategies for transitioning to low-carbon emission trucks in the United States. Retrieved from http://steps.ucdavis.edu/files/06-11-2015-STEPS-NCST-Low-carbon-Trucks-in-US-06-10-2015.pdf

67    Relaxed delivery times means a longer time period between request and delivery- for example instead of next day delivery, delivery is within two days.

developments, which support walking, cycling and potentially district energy. The increased density then facilities increased frequency of transit service or further transit investments, which then attract additional development. This kind of feedback effect provides a case for investment in transit infrastructure that is not reflected in the modelling results.

Personal VKT decline significantly for trips within the City boundaries, but continue to climb for trips into and out of Toronto, highlighting the need for regional planning efforts.
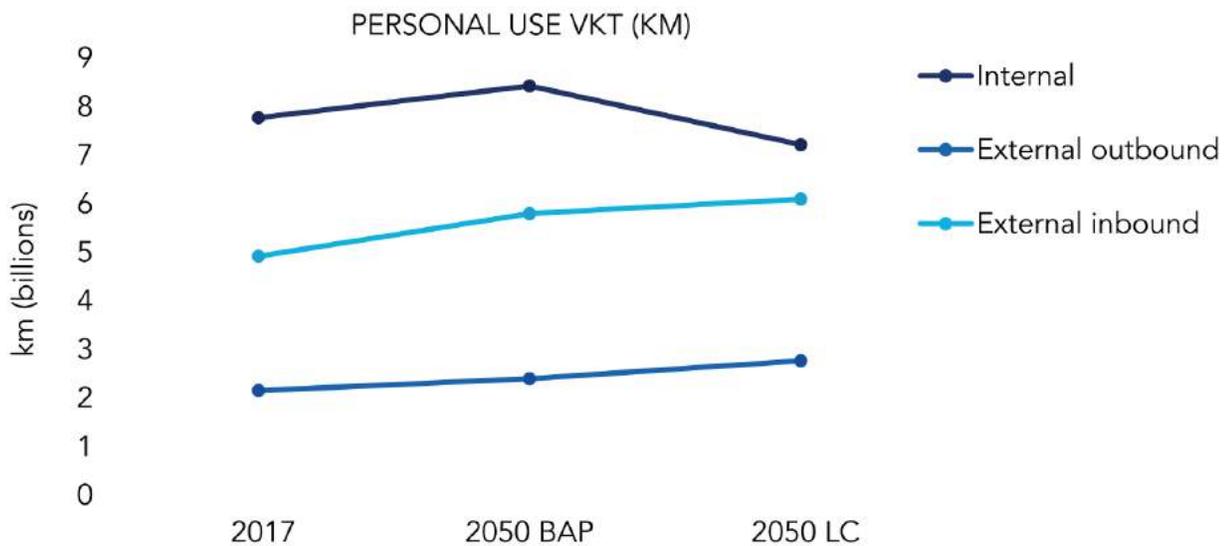


*Figure 25. Personal use VKT.*

The spatial analysis of per capita VKT illustrates an expansion of the area with lower VKT around the downtown core; this is as a result of shifts to active modes, congestion charges and enhanced transit. Figure 26 and Figure 27 illustrate the spatial distribution of home-based VKT per person. Home-based trips are trips for which one end of the trip is home. Enhanced transit is evident in the decreased per capita VKT along major transit routes as modelled in Figure 21; however the general pattern of increasing per capita VKT as the distance from the downtown increases remains.

CITY OF TORONTO HOME-BASED VEHICLE KILOMETERS TRAVELLED PER CAPITA BY ZONE, BUSINESS AS PLANNED SCENARIO, 2050



Legend
vehicle kilometers travelled (km/capita/yr)

- 0 - 1,300
- 1,300 - 2,000
- 2,000 - 2,300
- 2,300 - 2,700
- 2,700 - 4,800
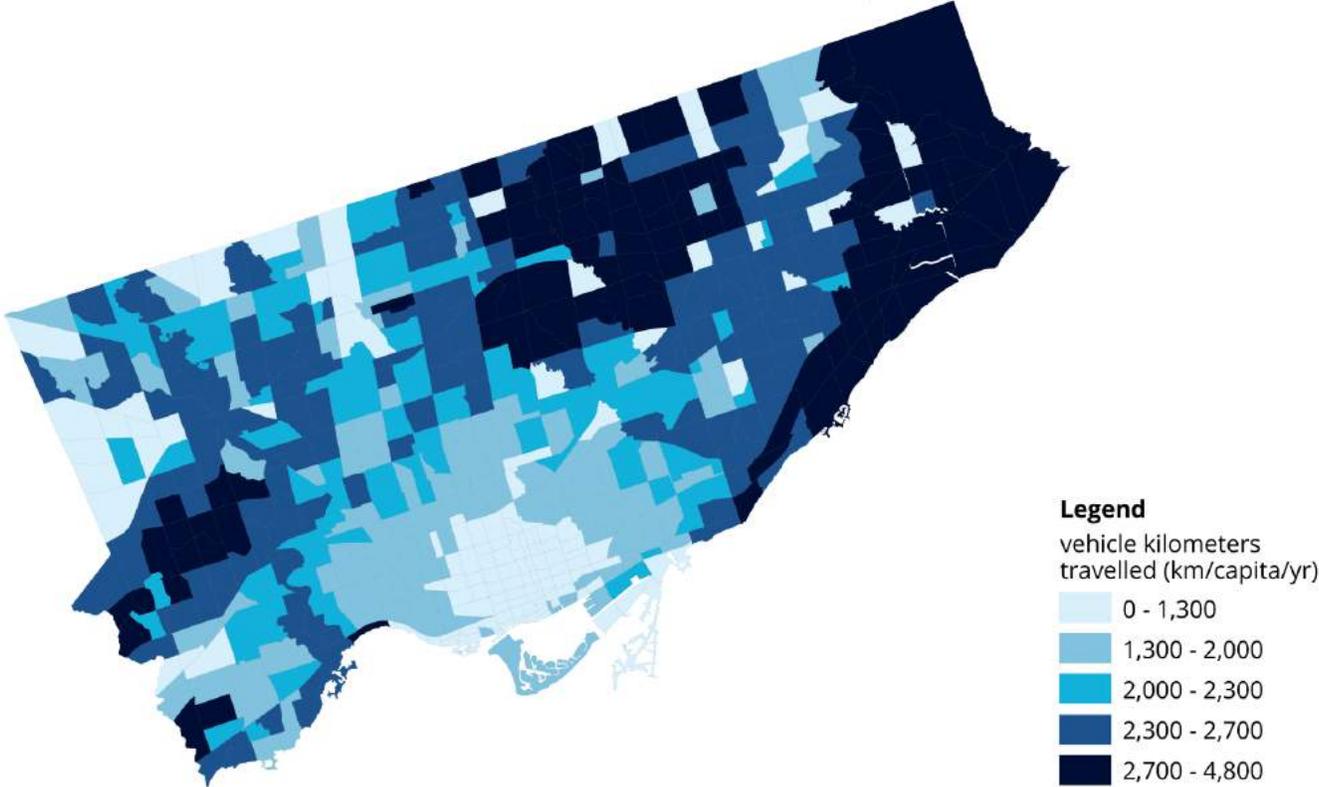
*Figure 26. Home-based VKT per capita by zone, BAP 2050.*

CITY OF TORONTO HOME-BASED VEHICLE KILOMETERS TRAVELLED PER CAPITA BY ZONE, LOW CARBON SCENARIO, 2050



Legend
vehicle kilometers travelled (km/capita/yr)

- 0 - 1,300
- 1,300 - 2,000
- 2,000 - 2,300
- 2,300 - 2,700
- 2,700 - 4,800
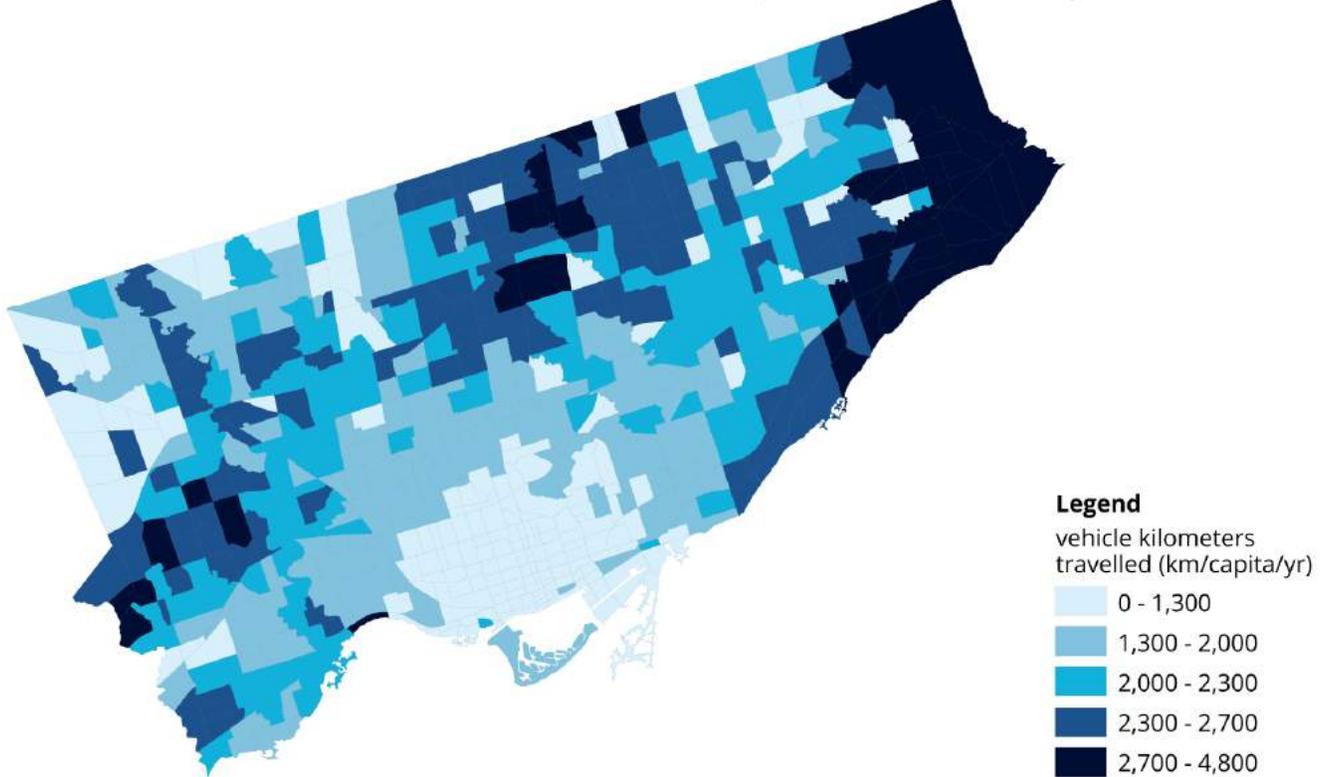
*Figure 27. Home-based VKT per capita by zone, LCS 2050.*

PERSON TRIP MODE SHARE BY TRIP DISTANCE - BAP 2050
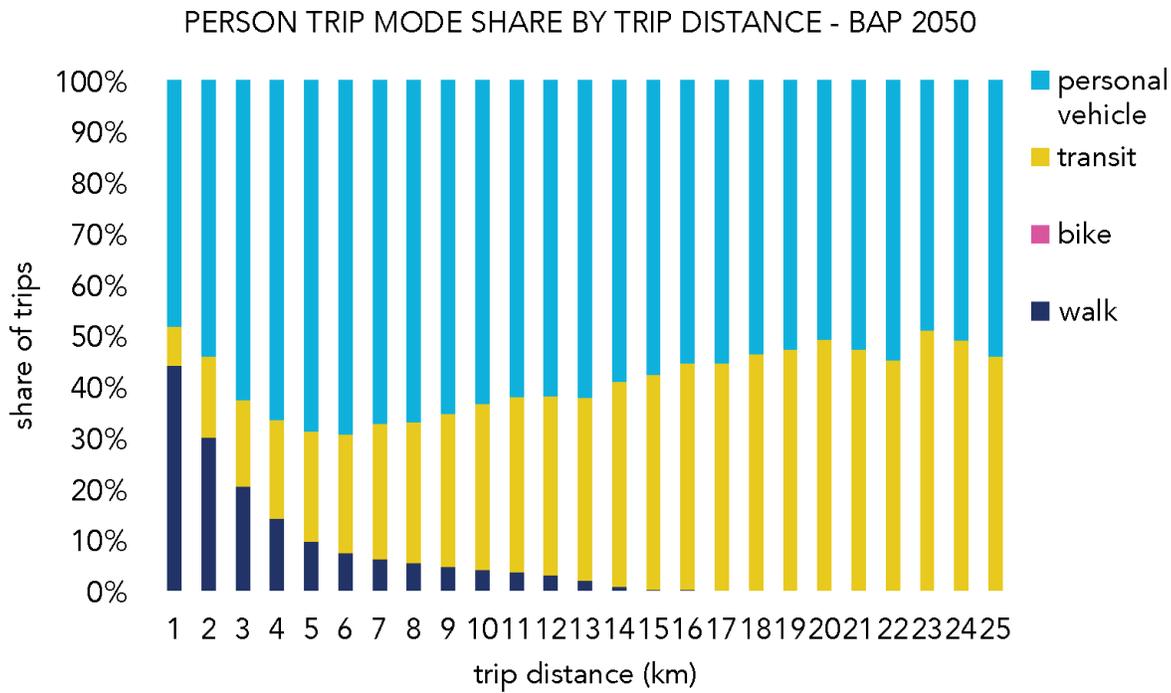
*Figure 28. Person trip mode share by distance, BAP 2050.*



PERSON TRIP MODE SHARE BY TRIP DISTANCE- LC 2050
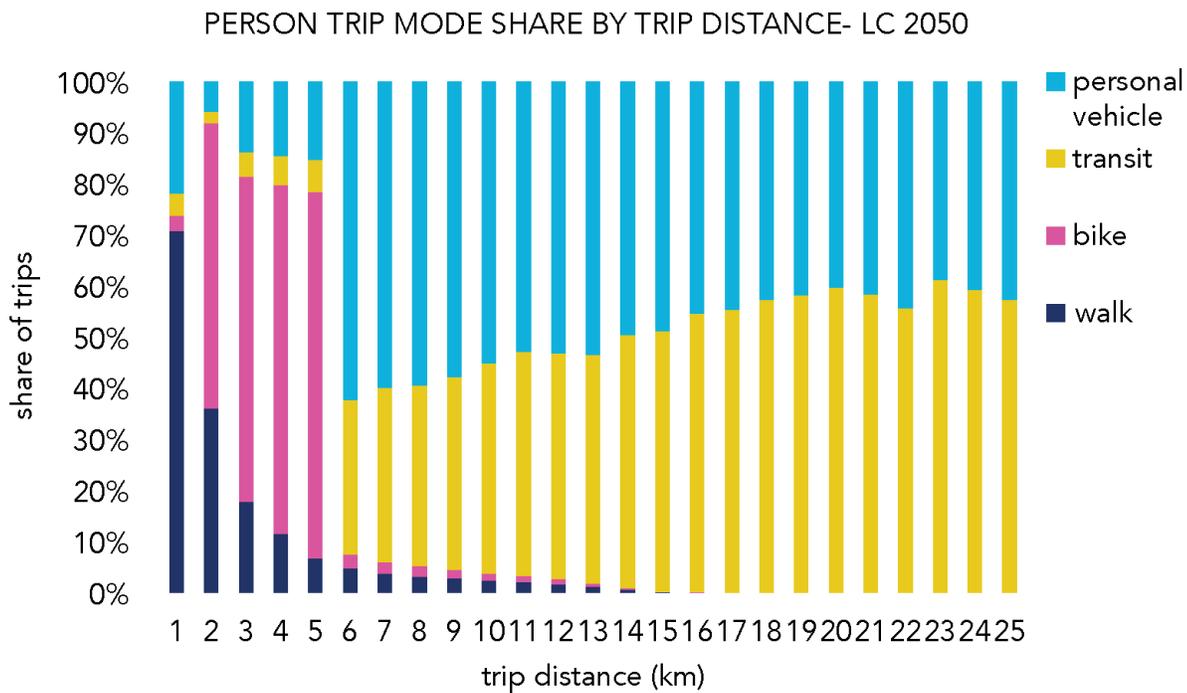
*Figure 29. Person trip mode share by distance, Low Carbon 2050.*

Walking and cycling modes experience significant gains in the LCS over the BAP scenario, together representing more than 40% of trips within the city. Vehicular mode share falls to 32%, for internal trips but it is persistently high for external trips, at 83% for trips out of the city and 63% for inbound trips. No major shifts for external inbound or outbound trips are achieved.

The impact of the actions in the LCS is evident in Figure 28 and Figure 29, which illustrate mode share by trip length as a percentage of the total. In Figure 28, active trips decline to 0% when the trip length reaches 15 km. In Figure 29, the share of walking and cycling trips for short trips increases significantly, while the share of vehicle trips declines for shorter trips. Longer trips are dominated by vehicles and transit.

Average vehicle trip length increases for all trip types, as illustrated in Figure 30, and is a result driven primarily by the introduction of autonomous vehicles. Interestingly, average vehicle trip length for internal trips increases in the LCS. Residents drive less overall, but when they do drive, they are generally making longer trips (> 5 km), resulting in a higher average vehicle trip length compared with BAP.
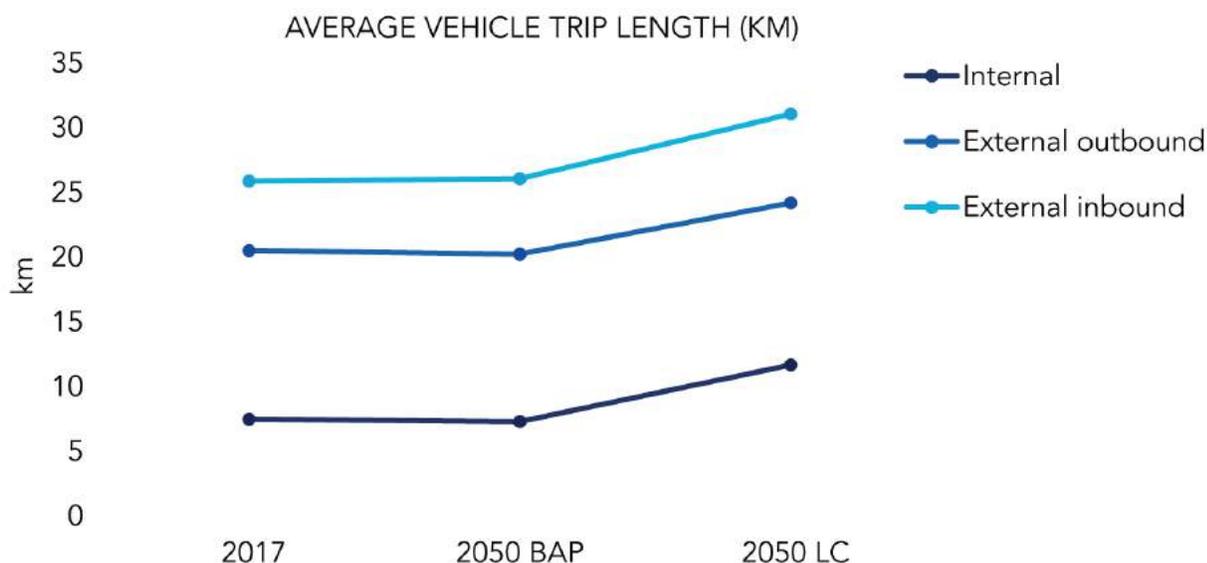


Figure 30. Average vehicle trip length.

# 4.5 Waste

*LCS Modelling Assumption: Waste diversion is enhanced.*

The Draft Strategy for a Waste Free Ontario includes the two goals of zero waste in the province and zero greenhouse gas emissions from the waste sector. Building on the City's existing target of 70% diversion by 2026 , a target of 95% diversion by 2050 was modelled. Additionally, 95% of the methane produced from anaerobic digestion and compost is captured for use as biogas (renewable natural gas).

The cogeneration facility at Ashbridges Bay treatment facility was modelled in the BAP. In the LCS, 2.1 MW of cogeneration was added at Highland Creek and 95% biogas (renewable natural gas) recovery was used to displace natural gas usage Humber treatment facilities.

*Observations*

The LCS continues the trajectory identified in the City's existing Long-Term Waste Management Strategy beyond 2026, resulting in very little waste going to landfill by 2050, approximately 0.03 tonnes per capita. No additional activities beyond the implementation of the Strategy are necessary to achieve this target in the short term.

# 5.   Integration

Following the analysis of each action, an integrated scenario was developed in which all the actions were modelled together, capturing feedback between the actions. For example, when modelled against the BAP scenario, shifts to walking reduce gasoline if a vehicle trip is avoided. However, in the integrated LCS, because of the widespread adoption of of electric vehicles in 2030, shifts to walking after 2030 reduce electricity consumption instead of gasoline, resulting in a significantly lower GHG reduction impact.

To illustrate this effect, the sum of the actions modelled individually is 10.4 Mt CO2e, however when they are modelled in an integrated scenario, this total declines to 8.7 Mt CO2e.

The order in which the actions are modelled influences the impact of each action. The approach used for the LCS applies the concept of reduce-improve-shift, whereby model actions that reduce consumption and maximize efficiency are prioritized and deployed in the model first, before other fuel switching actions; for example, mode share shifts to walking and cycling are prioritized over the electrification of the vehicle fleet.

Once the results of the integrated scenario were calculated, the proportionate reductions from each action were distributed on a year over year basis to generate a wedge diagram, illustrated in Figure 31.  The wedge diagram shows the contribution of each action to the overall emissions reduction trajectory. As there are dependencies and feedback cycles between the actions, which are captured by the model, the wedge diagram represents a simplified representation of the results.

The pathway descends from 19.7 Mt CO2e in the baseline year of 2011 to 3.9 Mt CO2e by 2050. This result represents an 85% reduction over the 1990 baseline of 27 Mt CO2e.  The emissions reduction contribution of each action in the year 2050 is shown in Table 5.

*Table 5. Emissions reduction results of actions, kt CO2e in 2050.*

| # | ACTION | KT CO2e (2050) |
|---|--------|----------------|
| | **LAND USE** | |
| 1 | Concentrate future development in areas appropriate for district energy and accessible to rapid transit. | 3 |
| | **BUILDINGS** | |
| | *Future buildings* | |
| 2 | Incorporate the rate of building demolition as new buildings replace existing buildings. | 62 |
| 3 | Reduce dwelling unit size. | 46 |
| 4 | Reduce commercial floor space per employee. | 35 |
| 5 | Apply Toronto Green Standard to new buildings. | 1,348 |
| | *Existing buildings* | |
| 6 | Retrofit multi-unit residential buildings pre-1984 (Tower Renewal+). | 261 |
| 7 | Retrofit of multi-unit residential buildings post 1984. | 92 |
| 8 | Retrofit older homes (HELP+) (pre 1980). | 238 |
| 9 | Retrofit newer homes (HELP+) (post 1980). | 34 |
| 10 | Retrofits for commercial and office buildings (BBP+). | 490 |
| 11 | Apply the Toronto Green Standard when buildings are renovated. | 471 |
| 12 | Re-commissioning of commercial buildings on an ongoing basis. | 49 |
| | **ENERGY SYSTEM** | |
| 13 | Incorporate solar photovoltaic systems into new construction. | 33 |
| 14 | Incorporate solar photovoltaic systems on roofs of existing buildings. | 72 |
| 15 | Develop offshore wind turbines. | 6 |
| 16 | Apply integrated solar thermal and solar photovoltaic systems to facades. | 67 |
| 17 | Expand zero carbon district energy systems:<br>17-1: deepwater cooling<br>17-2: captured waste heat<br>17-3: geothermal | 428<br>109<br>143<br>176 |
| 18 | Install electric heat pumps for space heating. | 882 |
| 19 | Install distributed energy storage. | 63 |
| 20 | Increase the use of renewable natural gas in district energy systems. | 344 |

| # | ACTION | KT CO2e (2050) |
|---|--------|----------------|
| | **TRANSPORTATION** | |
| 21 | Condensed work week/four day work week. | 59 |
| 22 | Integrated transit improvements. | 31 |
| 23 | Introduce transit in areas with high density and insufficient transit. (result N/A; see page 27) | - |
| 24 | Car free areas. | 69 |
| 25 | Personal transportation planning (Smart Commute+). | 18 |
| 26 | Increased cycling mode share. | 93 |
| 27 | Increased walking mode share. | 4 |
| 28 | Electrify transit fleet. | 239 |
| 29 | Introduction of autonomous vehicles/car sharing. | -361 |
| 30 | Increased adoption of electric vehicles. | 1,945 |
| | **INDUSTRY** | |
| 31 | Industrial process efficiency improvements. | 166 |
| | **FREIGHT** | |
| 32 | Implement strategies to reduce emissions associated with the last mile of delivery. | 140 |
| 33 | Transition to zero emissions vehicles. | 780 |
| 34 | Electrify the City vehicle fleet. | 12 |
| | **WASTE** | |
| 35 | Increase waste diversion rates. | 363 |
| 36 | Generate biogas from wastewater. | 90 |
| | **TOTAL** | 8,669 |

The integrated scenario provides additional insights. For example, one of the perceived barriers to widespread EV uptake was that the electrification of vehicles would require significant investments in the grid to service new electrical loads, however the integrated scenario shows that new electrical loads can be managed in the context of the overall energy system. The LCS sankey diagram in Figure 34, indicates that overall consumption of electricity decreases slightly compared with BAP sankey in Figure 34, despite major emphasis on fuel switching to electricity, particularly in the transport sector. This reduction is a result of the increased efficiencies in the building stock, which exceed the addition of new electricity consumption from vehicles and the addition of heat pumps. While electricity is relatively low carbon, it is important to focus on the electricity reductions in buildings so that fuel switching to electricity in buildings and transportation does not result in overall increases in electricity.

EMISSIONS RESULTING FROM THE ACTIONS MODELLED IN THE
CITY OF TORONTO INTEGRATED LOW CARBON SCENARIO, 2016 - 2050
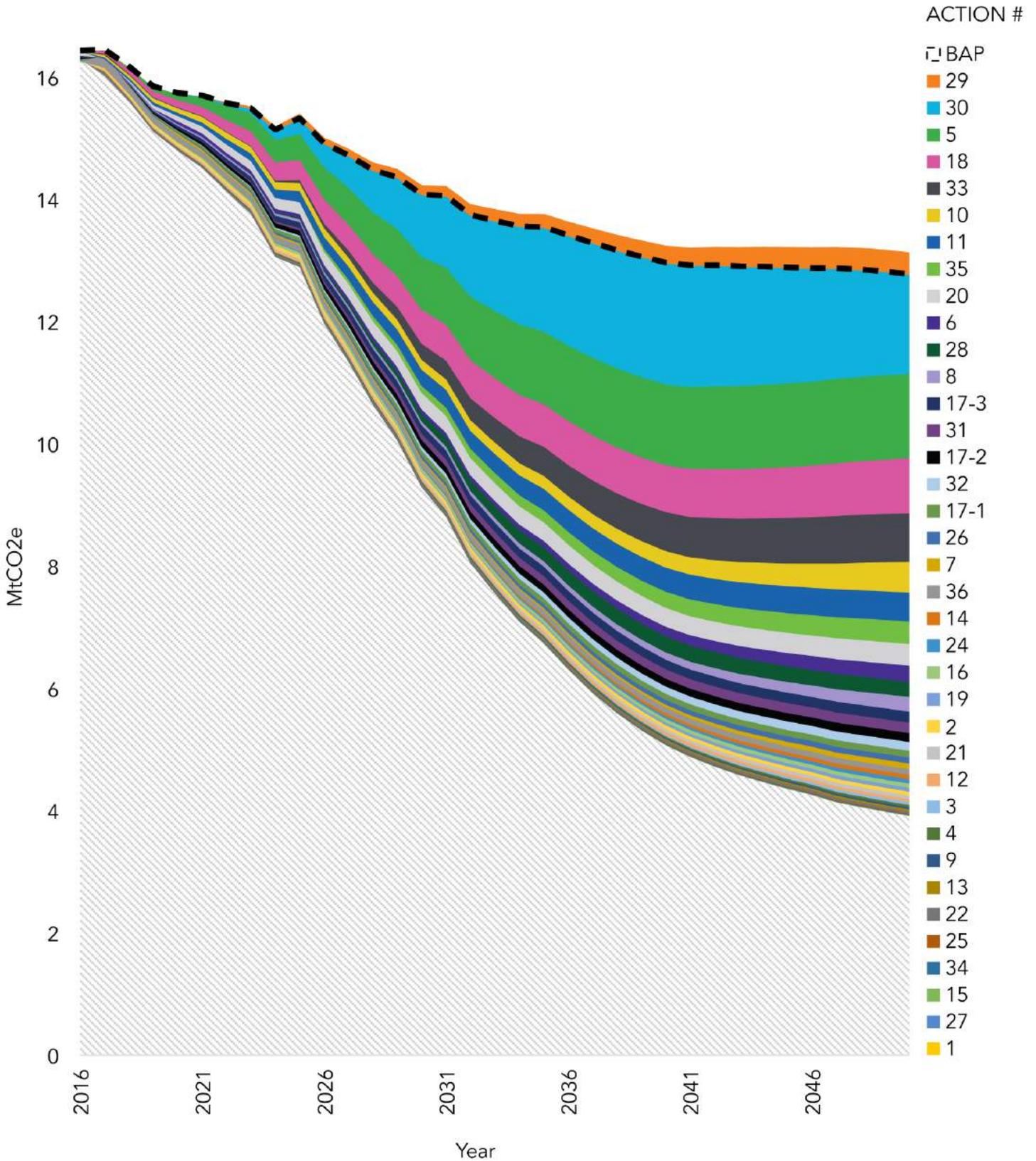
*Figure 31. Wedges diagram for the low carbon scenario*

# CITY OF TORONTO EMISSIONS REDUCTION ACTIONS
## WEDGES GRAPH - LEGEND

☐ BAP
- 29. Autonomous vehicles
- 30. Increase adoption of EV
- 5. TGS for new buildings (res & non-res)
- 18. Electric heat pumps
- 33. Zero emissions vehicles for freight
- 10. Retrofit ICI
- 11. TGS for renovations
- 35. Increase waste diversion
- 20. Increase renewable natural gas in DE
- 6. Residential retrofit pre-1984 (Tower Renewal+)
- 28. Electrify transit fleet
- 8. Dwelling retrofit pre-1980 (HELP+)
- 17-3. Expand DE - geothermal
- 31. Industrial process efficiency
- 17-2. Expand DE - waste heat
- 32. Last mile solutions in freight
- 17-1. Expand DE - deepwater cooling
- 26. Increased cycling mode share.
- 7. Residential retrofit post 1984 (Tower Renewa+l)
- 36. Generate biogas from wastewater
- 14. Solar PV existing buildings
- 24. Car free areas
- 16. Integrated solar thermal & PV on facades
- 19. Energy storage
- 2. Incorporate demolition rate
- 21. Condensed work week
- 12. Re-commissioning commercial buildings
- 3. Reduce dwelling unit size
- 4. Reduce commercial floor space per employee
- 9. Dwelling retrofit post 1980 (HELP+)
- 13. Solar PV new construction
- 22. Integrated transit improvements
- 25. Personal transportation planning
- 34. Electrify City vehicle fleet
- 15. Offshore wind
- 27. Increased walking mode share
- 1. Concentrate future residential development

## 5.1 Declining energy consumption

The LCS results in a gradual decrease in overall energy consumption to 2050, with significant decreases in the transportation sector, illustrated in Figure 32, as gasoline and diesel consumption decline, illustrated in Figure 33. Increases in renewable sources of energy are evident, in particular geothermal, as more renewables come online.
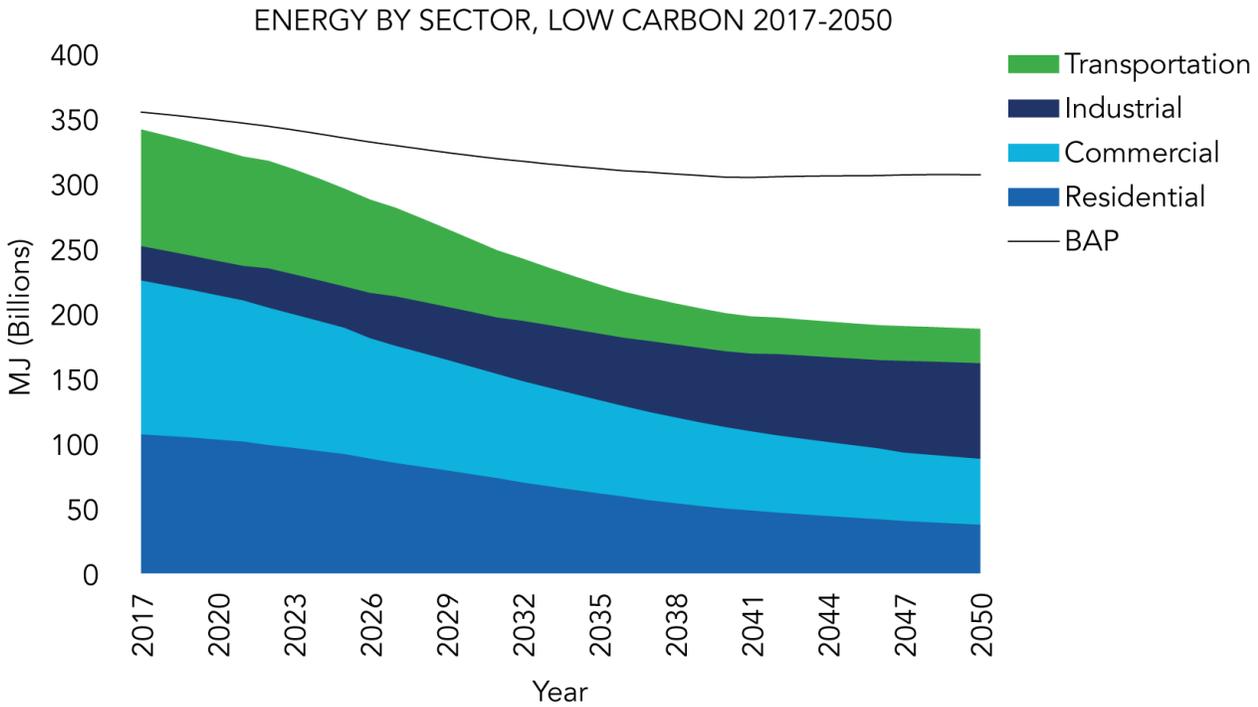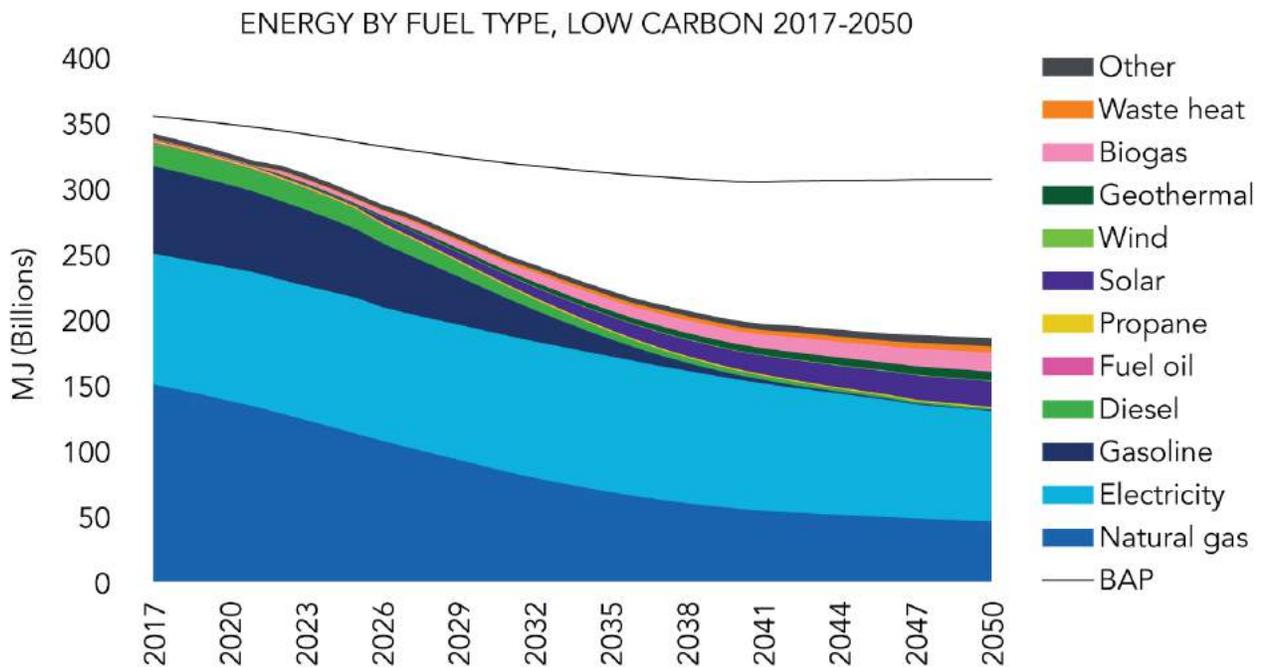


*Figure 32. Energy by sector, Low Carbon 2017-2050.*


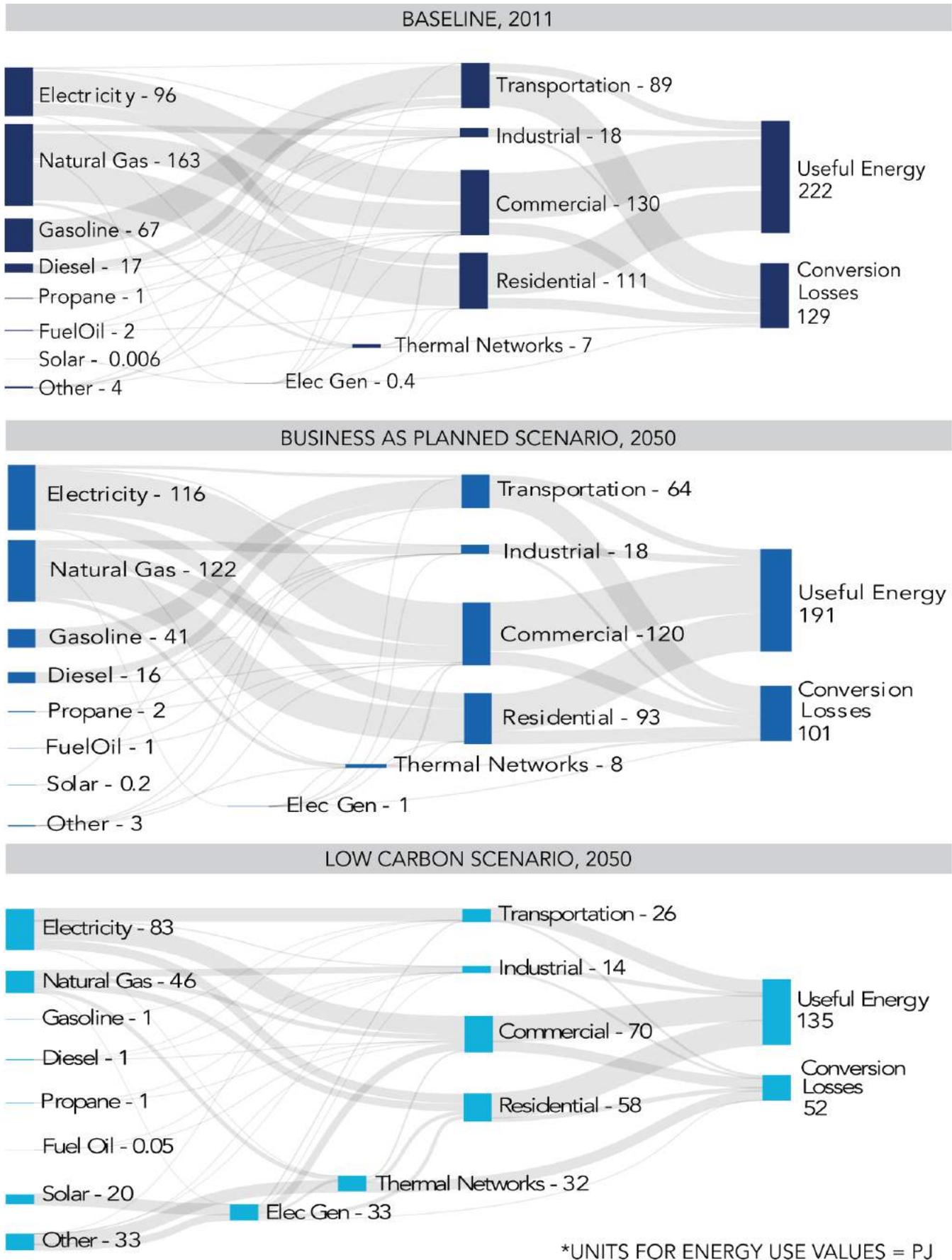
*Figure 33. Energy by fuel, Low Carbon 2017-2050.*

*Figure 34. Sankey, Baseline, BAP, and LCS.*

The sankey diagrams show that the energy system in Toronto becomes more complex in the LCS sankey, with a greater diversity of fuels and generation technologies gaining prominence, as illustrated both by the number of lines and the thickness of the lines, in comparison with the BAP sankey.

Energy in transportation declines from 63.9 PJ to 26.4 PJ, primarily due to the increased efficiency of electric vehicles over internal combustion engines. Another dramatic change is the growth of thermal networks, from 7.5 PJ in the BAP to 32 PJ in the LCS. Decentralized electrical generation also increases from 0.7 PJ in the BAP to 32.6 PJ in the LCS. The category of other as a fuel source includes geothermal and biogas. Around 2035, the gains in thermal envelope efficiency exceed the increased electricity consumption as a result of fuel switching so that total electricity use declines in the later years.

Figure 35 and Figure 36 illustrate the transition of the emissions profile of the city by energy sources and by sector. Emissions from gasoline and diesel used for transportation in Figure 35 all but disappear in Figure 36. Emissions from natural gas consumption in the residential and commercial sectors are similarly reduced, but do not disappear. Emissions from electricity are more or less constant in the residential sector but decline in the commercial sector.

*Observations*

The integrated scenario captures the effects that each of the actions have on one another, emphasizing the importance of analyzing GHG emissions of the whole system. An analysis of an action in isolation of other actions will likely overstate the potential of the GHG emissions reductions.

The wedges diagram is a representation of the relative impact of each of the actions, but the interdependencies between the actions means that it is an incomplete picture. For example, if electric vehicles are implemented in the absence of efforts to reduce VKT, the GHG emissions reduction associated with the electric vehicles is higher. As another example, if heat pumps are modelled without consideration of building retrofits, the GHG emissions reduction associated with the heat pumps is also higher.

By 2050, the pathway to phase out gasoline and diesel in the transportation sector is apparent, but challenging; it relies primarily on electrification of the entire vehicle fleet. Reductions in VKT as a result of mode shifting or travel reduction decrease the cost of this transition and increase the co-benefits as described later in the report.

The pathway to substantially reduce natural gas consumption is also clear, through retrofits, improved efficiency in new construction, district energy and fuel switching to heat pumps, but eliminating natural gas entirely requires more time because the turnover in the stock of buildings is slower than that of vehicles. Completely removing natural gas from the building sector, which

EMISSIONS BY SECTOR AND FUEL/SOURCE, BAP 2050
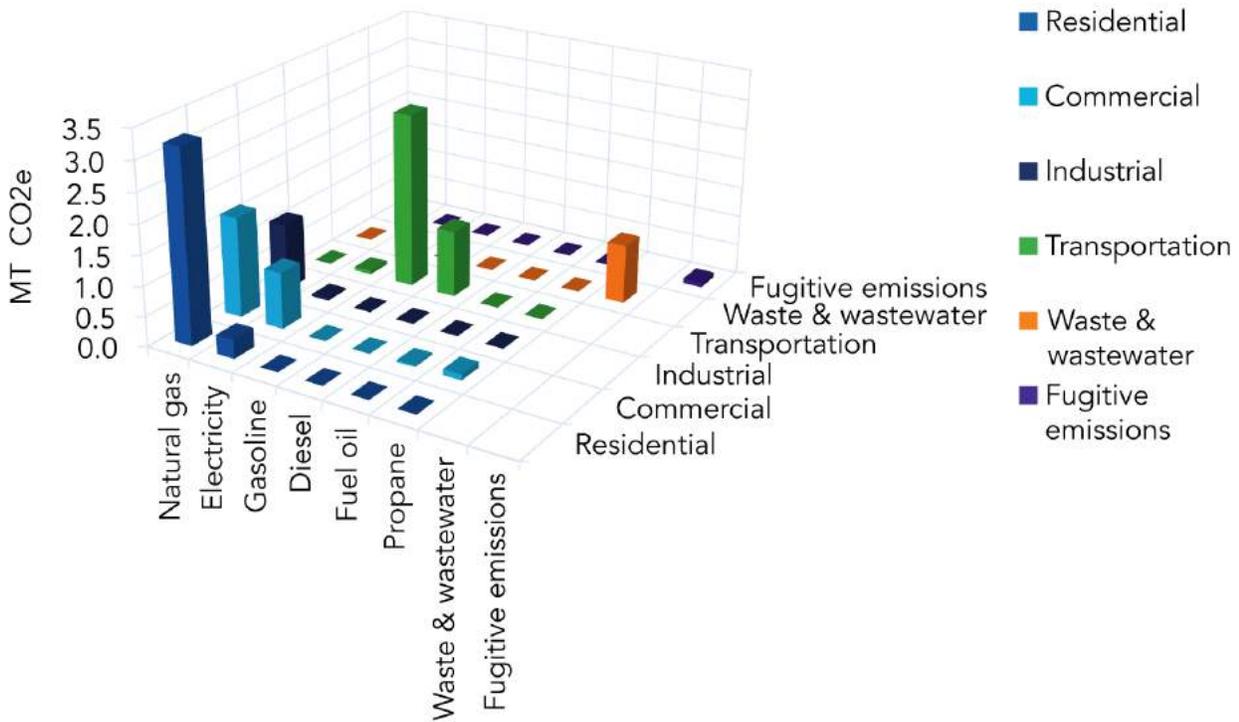
Figure 35. Emissions by sector and fuel, BAP 2050.



EMISSIONS BY SECTOR AND FUEL/SOURCE, LOW CARBON 2050
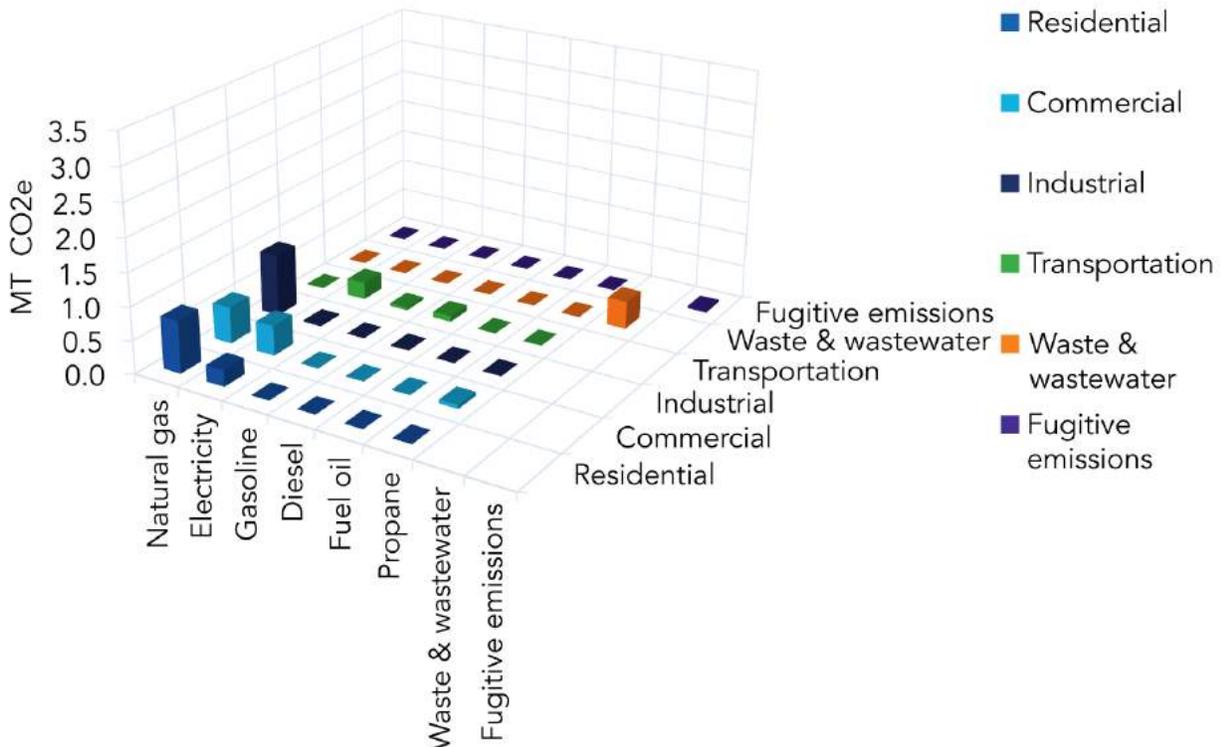
Figure 36. Emissions by sector and fuel, Low Carbon 2050.

was not represented in the LCS, would require some combination of a more aggressive introduction of heat pumps, major new sources of renewable natural gas and/or the introduction of technologies not yet considered.

The energy system in the LCS integrated scenario is more decentralized than in the BAP. More energy is generated in different locations, including using PV and in district energy systems, which increases the resilience of the energy system as a whole. The emphasis on decentralized energy represents a transition away from the traditional utility model, providing new opportunities for many different types of entities to become energy providers, potentially supported by utilities. The energy system as a whole is more efficient, with conversion losses reduced from 36% of total energy generated in the system to 28% in the LCS, primarily because of the efficiency of electric vehicles over internal combustion engines.

# 6. Co-benefits and co-harms

The purpose of Chapter 6 is to assess corollary impacts resulting from the LCS over the BAP scenario, answering the following questions. What additional benefits results from implementing the LCS beyond GHG emissions reductions? What are potential negative impacts and how might they be mitigated? Corollary impacts are defined as the corollary benefits (co-benefits) or harms (co-harms) that result from the LCS, in the aspects of health, social equity and economic prosperity.  The Chapter does not address all potential impacts but provides insight on many relevant to different objectives of the City of Toronto. A literature review titled Co-benefits and co-harms of Climate Action Report informed this chapter.

In addition to considering GHG emissions, the consideration of co-benefits and co-harms can strengthen societal efforts to reduce GHG emissions for the following reasons:[68]

- Synergies are the opportunity to achieve two objectives at once. In many cases the actions in the LCS achieve socio-economic objectives, but in other cases the synergy is contingent on careful consideration of the way in which the action is implemented. Consideration of synergies can also ease the implementation of an action, by generating a broader field of support.

- The urgency to achieve emissions reductions is about avoiding loss of inertia, lock-in effects, irreversible outcomes, and/or elevated costs. The co-benefits described below have their own inherent sense of urgency, resulting from the need to address other societal objectives.

- Costs of early action are generally lower than later action, both for GHG reductions and co-benefits, because delayed action involves ongoing investments in infrastructure, activities and utilities that can be forfeited. Consideration of co-benefits can unlock new opportunities for capital and savings that are not apparent in considering only GHG impacts.

- The longevity of planning and development decisions locks cities into the effects of these decisions for decades, if not centuries. GHG emissions reductions on their own are unlikely to be a sufficient argument to influence the planning process.

- Distribution effects: Low carbon actions have different impacts on different subsets of the population. The impacts of the actions are experienced differently depending on factors that include income level, age, generation and race. Without consideration of co-benefits and co-harms, there is a risk that some actions to reduce GHG emissions may increase inequity or further marginalisation.

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68    Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. M. (2015). Decarbonizing development: three steps to a zero-carbon future. Washington, DC: World Bank Group

In many cases, actions that reduce GHG emissions in cities correspond to or directly overlap with actions that create a vibrant cityscape, improve public health outcomes, reduce municipal operating and capital costs, and support innovation; these are no-regrets policies in that they deliver social, environmental and economic benefits.[69]

## *Co-benefits can exceed the GHG reduction benefit.*

One review of more than a dozen studies on GHG mitigation policies found that the co-benefits of reduced air pollution—a single co-benefit—often equaled or exceeded the benefit of the GHG reduction itself.[70]

## *Co-harms can be reduced or eliminated.*

- While there are many co-benefits associated with low carbon actions, there is also potential for co-harms and negative feedback cycles. For example:

- Compact urban development reduces emissions in part by making communities walkable and so reducing car use, but without careful design there is a risk that people, including children, will be exposed to elevated levels of air pollutants as they walk or cycle in close proximity to traffic.

- The desirability of compact urban development can lead to the exclusion of individuals with lower incomes or different needs if counteracting strategies are not employed.

- Infrastructure to reduce emissions will require major investments and depending on which entities make those investments, there may be distributional effects that favour households with higher incomes at the expense of those with lower incomes.

In almost every such case, however, negative impacts be can be mitigated or reversed by policy design that considers not only GHG emissions but also health and equity impacts.

## *Reducing GHG emissions is a massive economic opportunity.*

The transition to a low carbon economy represents a massive economic opportunity for local workforce development. One analysis pegged the global economic opportunity of investments in low-carbon urban actions at $16.6 trillion globally —the financial savings resulting from energy savings and lower cost generation in transportation, buildings and waste sectors.

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69    Kamal-Chaoui, L., & Robert, A. (2009). Competitive cities and climate change. Retrieved from http://www.oecd-ilibrary.org/governance/competitive

70    OECD. (2000). Ancillary Benefits and Costs of Greenhouse Gas Mitigation. OECD Publishing.

The City of Toronto is well positioned to build on this opportunity with strengths in information technology and innovation, and a population that is globally connected. By advancing low carbon actions, the City of Toronto is developing private and public sector capacity to engage in this economic opportunity.

### *Energy efficiency represents the greatest value.*

Avoided energy has been re-conceptualized as the "first fuel", a source of energy which merits investments ahead of other more complex and costlier sources of energy. Investment globally on energy efficiency was two-thirds greater than investment in conventional power generation, corresponding with a decrease almost 2% in the energy used per unit of gross domestic product globally in 2014.[71] In addition to seizing the economic opportunity, energy efficiency also supports competitiveness and innovation, reduces municipal operating costs and capital costs, reduces household and business energy costs and improves housing quality.

### *Equity benefits are possible.*

There are clear equity benefits, from increasing access to destinations and improved living conditions through compact urban form and increased transit to lower household energy costs. However, equity benefits are contingent on the way in which the actions and policies are implemented. For example, the equity benefits of expanded transit are contingent on the introduction of affordability measures.

## Summary of impacts

A wide range of co-benefits and co-harms were evaluated as part of the TransformTO project, in some cases drawing on the results of the CityInSight modelling for insights.

Tables 6-8 provide an overview of the impacts of the LCS over the BAP scenario.

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71    International Energy Agency. (2016). Energy efficiency market report 2016. Retrieved from https://www.iea.org/publications/freepublications/publication/mediumtermenergyefficiency2016.pdf

*Table 6. Summary of health impacts*

| CO-BENE-FITS/ CO-HARMS | IMPACT OVERVIEW | LAND-USE | BUILDINGS | TRANS-PORTA-TION | ENERGY | WASTE |
|---|---|---|---|---|---|---|
| **1. HEALTH** | | | | | | |
| 1.1 Cleaner air | Improvement in air quality. | Conditional on design to reduce exposure of pedestrian to air pollution | | Improved: reduced combustion of gasoline in vehicles | Improved: reduced natural gas combustion | Improved: some reduced emissions from waste treatment processes |
| 1.2 A more active city | Increased active transportation mode share. | Improved: compact urban increases walking and cycling | | Improved: increase in walking and cycling trips | | |
| 1.3 A quieter city | Decreased engine noise. | | Improved: insulation in buildings reduces exterior noise | Improved: decreased engine noise from combustion engines | | |
| 1.4 Better access | Destinations are more accessible. | Improved: dwellings are located in closer proximity to commercial destinations | | Improved: dwellings are centered around transit corridors and hubs | | |
| 1.5 Social capital | People interact more as a result of mixed-use development and increased walking and cycling. | Improved: increased mixed-use spaces result in more mixing of people. | | Improved: people interact more when walking or cycling | | |
| 1.6 Healthier buildings | Building quality is improved. | | Improved: indoor environments from TGS and retrofits | | Improved: energy performance is enhanced | |

*Table 7. Summary of impacts on economic prosperity*

| CO-BENE-FITS/ CO-HARMS | IMPACT OVER-VIEW | LAND-USE | BUILDINGS | TRANSPOR-TATION | ENERGY | WASTE |
|---|---|---|---|---|---|---|
| **2. ECONOMIC PROSPERITY** | | | | | | |
| 2.1 New job opportunities | New employment opportunities are created. | | Improved: new jobs will be created in retrofits and as a result of enhanced building codes | Improved: new jobs will be created in manufacturing (eg. EVs) and other high tech sectors; jobs will be lost in maintenance. Jobs may also be lost as autonomous vehicles replace drivers of cabs and delivery vehicles and the overall vehicle fleet is smaller | Improved: new jobs will be created in supplying, installing and maintaining, solar PV, heat pumps, district energy | Improved: new jobs will be created in product design, re-use of materials, materials science, engineering, recycling and waste diversion |
| 2.2 Cost savings for households | The impact on household incomes is mixed. | Negative: increased intensification likely increases housing costs | Improved: operations costs of buildings declines | Improved: household energy costs from transportation decline | Negative: Household energy costs increase as a result of the introduction of new technologies | |
| 2.3 Economic development | Major new economic sectors emerge. | Improved: new investment opportunities in development | Improved: new investment opportunities in retrofits | Improved: new investment opportunities in vehicle fleets | Improved: new investment opportunities in renewable energy and district energy | Improved: new investment opportunities waste diversion |

| CO-BENE-FITS/ CO-HARMS | IMPACT OVER-VIEW | LAND-USE | BUILDINGS | TRANSPOR-TATION | ENERGY | WASTE |
|---|---|---|---|---|---|---|
| 2.4 Municipal finances | Municipal finances associated with existing services are more stable; New services are required. | Improved: reduced per dwelling unit servicing costs | Unknown: conditional on the policies and mechanisms to support retrofits | Unknown: conditional on the policies and mechanisms to support EVs and mode shifts | Improved: opportunities to generate financial returns from renewable energy generation | Likely improved: solid waste management costs will decline and revenue will be generated from waste |
| 2.5 Stimulating innovation | The Low Carbon Scenario will stimulate innovation. | Improved: new policy and fiscal mechanisms are required to support intensification | Improved: scaled up approaches to renovations, retrofits and green building technology | Improved: electric vehicles and autonomous vehicles | Improved: mass deployment of renewable energy systems | Improved: waste diversion strategies |
| 2.6 Reputation | The reputation of the City is enhanced. | Improved: the emphasis on intensification result in increased livability | Improved: high performance buildings are pioneered in Toronto | Improved: Toronto has an enhanced transit system | Improved: renewable energy and district energy increase exposure | Improved: very little waste goes to landfill |
| 2.8 Energy footprint | There are more opportunities for green space in the City. There is reduced pressure on green space outside of the City. | Improved: additional intensification may create additional opportunities for green space | | | Improved: energy generation in the city boundaries decreases the need for new capacity in green spaces beyond the city | |

*Table 8. Summary of impacts on social equity*

| CO-BENE-FITS/ CO-HARMS | IMPACT OVERVIEW | LAND-USE | BUILDINGS | TRANS-PORTA-TION | ENERGY | WASTE |
|---|---|---|---|---|---|---|
| **3. SOCIAL EQUITY** | | | | | | |
| 3.1 Poverty | Household energy costs increase but the cost of transportation decreases. | Negative: intensification can increase the costs of housing; could be mitigated by affordable housing policies | Improved: social housing is retrofit: operating costs of housing decline. | Improved: cost of moving around the city declines due to enhanced walking, cycling and transit, and overall VKT declines | Negative: participation in the RE economy may be limited for those in poverty; district energy can provide secure and cost effective heating and cooling | |
| 3.2 A city for the elderly | Accessibility for the elderly increases. The built environment is healthier | Improved: destinations are more accessible via walking, cycling and transit | Improved: buildings are healthier | Improved: walking and transit infrastructure. Autonomous vehicles represent a new option for travel | Improved: air conditioning is widespread reducing the impacts of heat waves | |
| 3.3 A child friendly city | Accessibility for children increases. The built environment is healthier. | Improved: destinations are easier to access by walking, cycling or transit | Improved: buildings are healthier | Improved: walking and transit infrastructure: autonomous vehicles represent a new option for travel | | |
| 3.4 Future generations | The burden on future generations is decreased. Stranded costs are avoided. | Improved: damage from climate change is reduced | Improved: damage from climate change is reduced | Improved: damage from climate change is reduced | Improved: damage from climate change is reduced: stranded costs are avoided | Improved: damage from climate change is reduced |

# 6.1 Advancing health

## 6.1.1 Cleaner air

Air quality in the Low Carbon Scenario is improved by reducing the combustion of fossil fuels in the geographic area of Toronto, including in the buildings, industry and transportation sectors.

CHANGE IN COMBUSTION OF FOSSIL FUELS FROM 2016 TO 2050
BUSINESS-AS-PLANNED (BAP) AND LOW CARBON SCENARIOS (LCS) IN
THE CITY OF TORONTO
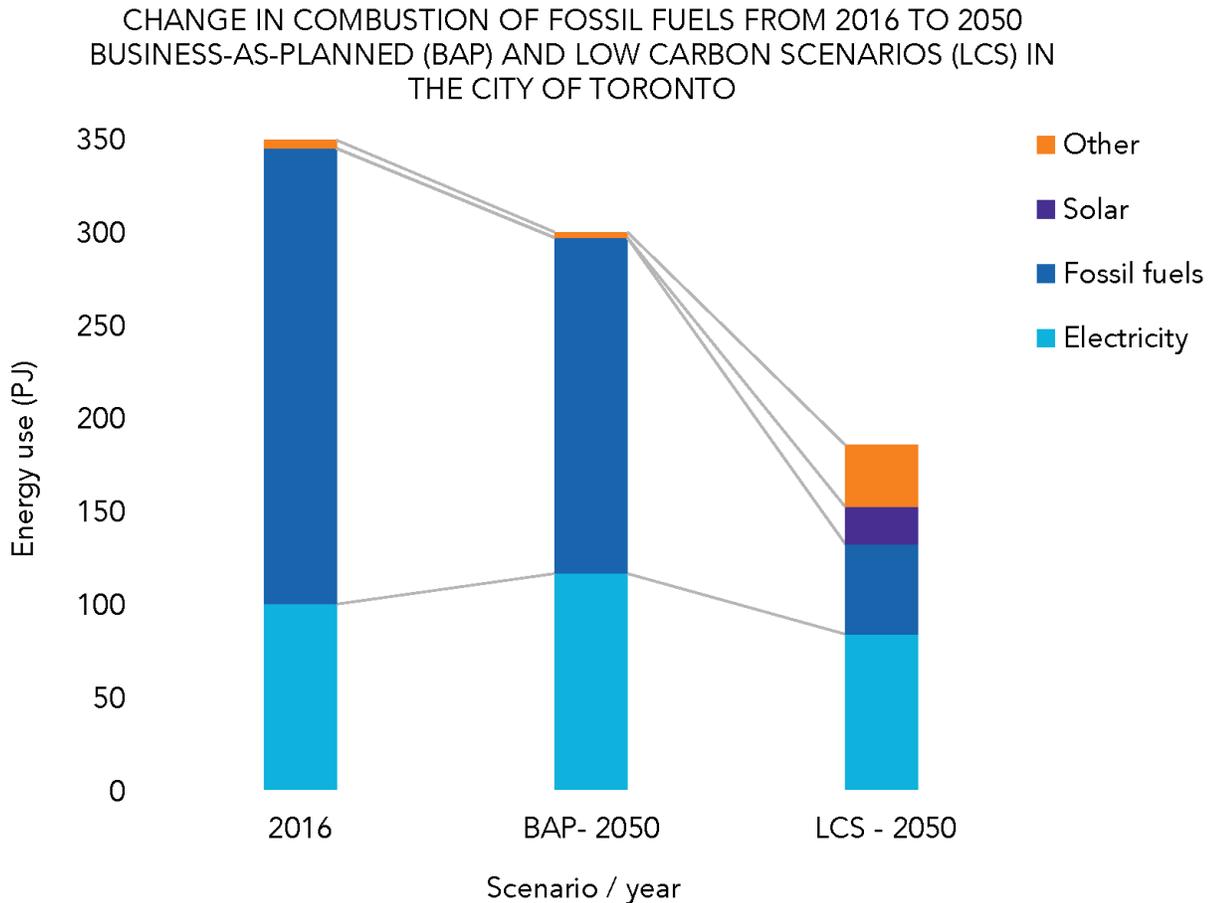


*Figure 37. Fossil fuels as a share of energy consumed.*

Combustion of fossil fuels declines by 80% between 2016 and 2050 in the LCS, from 245 PJ to 48 PJ. Of the 48 PJ, 94% of the fossil fuel consumption is natural gas. In 2050, the LCS represents a 73% reduction in fossil fuel combustion over the BAP scenario, which projects 180 PJ in 2050, as illustrated in Figure 37. Note that there are some fossil fuels used in the generation of electricity imported from the provincial grid that are not included in this total.

Air pollutants associated with the combustion of fossil fuels include sulphur dioxide, nitrogen oxides, ground-level ozone, particulate matter, carbon monoxide, volatile organic compounds and others. As fossil fuels are phased out, these pollutants will be reduced or eliminated, thereby reducing premature deaths and hospitalizations, which in 2014 were estimated at 280

and 1,090 respectively.[72] Other health benefits include decreased mortality from cardiovascular disease,[73] and decreased prevalence of asthma and allergic diseases.[74]  In 2014, air pollution from traffic alone contributed to 800 episodes of acute bronchitis among children, 42,900 asthma symptom days, mostly among children, 43,500 days where respiratory symptoms such as chest discomfort, wheeze, or sore throat would be reported and 128,000 days when people would stay in bed or otherwise cut back on normal activities.[75]

In the LCS these impacts would be substantially mitigated due the reduction in fossil fuel combustion, particularly in the transportation sector.

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72    City of Toronto. (2014). Path to healthier air: Toronto air pollution burden of illness update.

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

74    Bowatte, G., Lodge, C., Lowe, A., Erbas, B., Perret, J., Abramson, M., … Dharmage, S. (2015). The influence of childhood traffic-related air pollution exposure on asthma, allergy and sensitization: a systematic review and a meta-analysis of birth cohort studies. Allergy, 70(3), 245–256.

75    City of Toronto. (2014). Path to healthier air: Toronto air pollution burden of illness update.

## 6.1.2 A more active city

INCREASE IN ACTIVE TRAVEL IN THE CITY OF TORONTO LOW CARBON SCENARIO OVER THE BUSINESS AS PLANNED SCENARIO, 2050
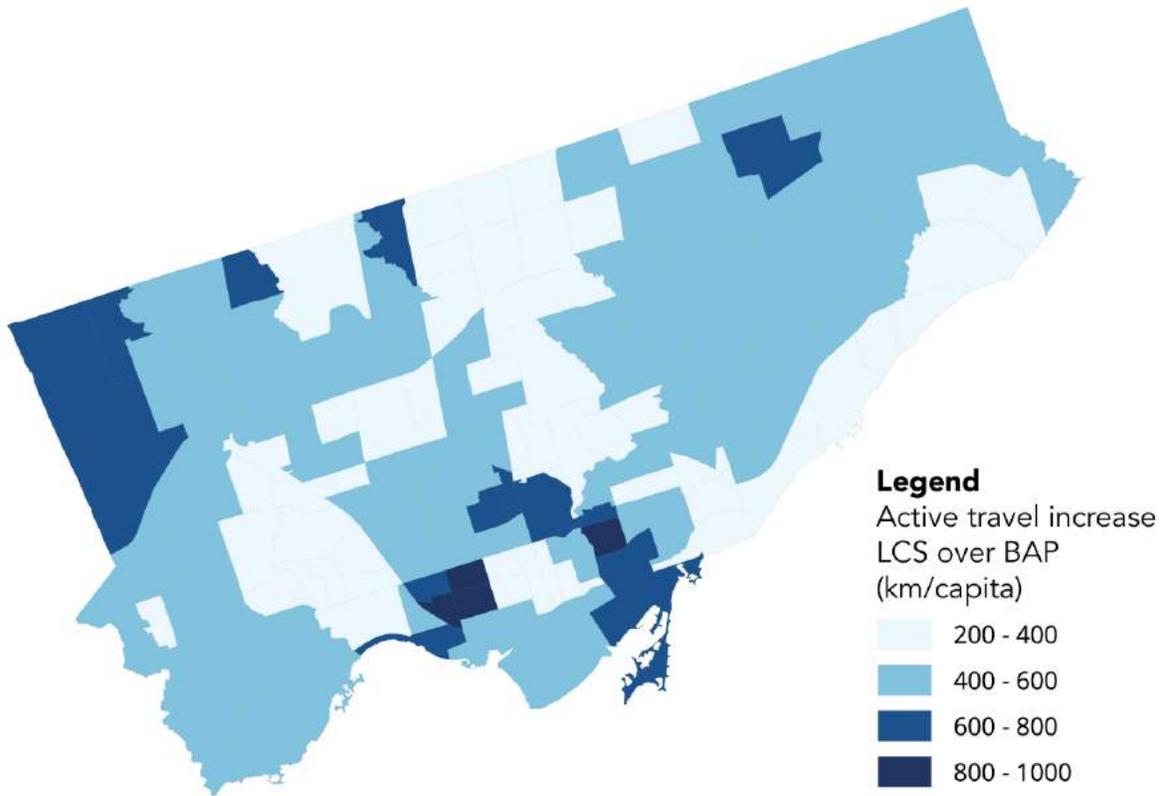


*Figure 38. Increase in km of active transportation in the LCS over BAP by neighbourhood.*

Walking and cycling rates increase dramatically in the LCS over the BAP, which implies both increased frequency of cycling trips, but also that a broader swath of the population will be cycling and walking. The variation in increase between neighbourhoods[76] in Figure 38 is a function of different levels of opportunity to reduce trips based on the existing active transportation mode share, trip length, and proximity to destinations and access to transit.

---

76   Spatial analysis for co-benefits and co-harms has been completed using the neighbourhood spatial disaggregation in order to apply indicators developed by Wellbeing Toronto. Details on the neighbourhoods are available here: http://map.toronto.ca/wellbeing

**Legend**
km increase LCS over
BAP (millions)

- 2 - 15
- 15 - 28
- 28 - 41
- 41 - 55
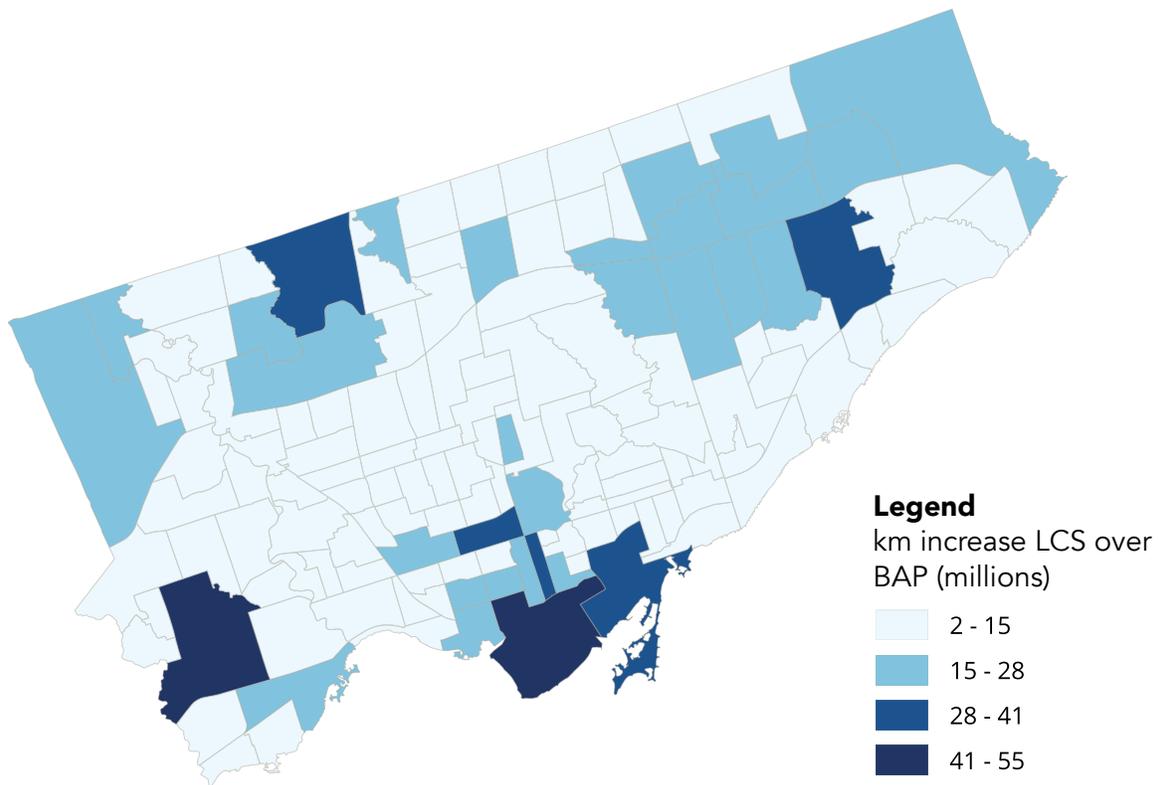
*Figure 39. Increase in walking cycling km in LCS over BAP by neighbourhood.*

Total kilometres walked or cycled in the LCS climbs to 2.4 billion kilometres
in 2050 versus 730 million in the BAP scenario, an increase of 320%. The
benefits of the additional exercise are wide ranging and studies in other
cities, have indicated that the relative risk of all cause mortality was 30-40%
less among those who cycled compared to those who did not undertake
comparable levels of exercise. Physical activity is also positively associated
with improved mental health, specifically lower levels of anxiety and
depression, and positive mood.

## 6.1.3  A quieter city



CHANGE IN VEHICLE KILOMETERS TRAVELLED (VKT) IN THE CITY OF TORONTO LOW CARBON SCENARIO (LCS) VERSUS BUSINESS AS PLANNED (BAP) SCENARIO, 2050

**Legend**
VKT LCS over BAP
(x100,000 km/yr/zone)

- -600 - -400
- -400 - -200
- -200 - 0
- 0 - 89
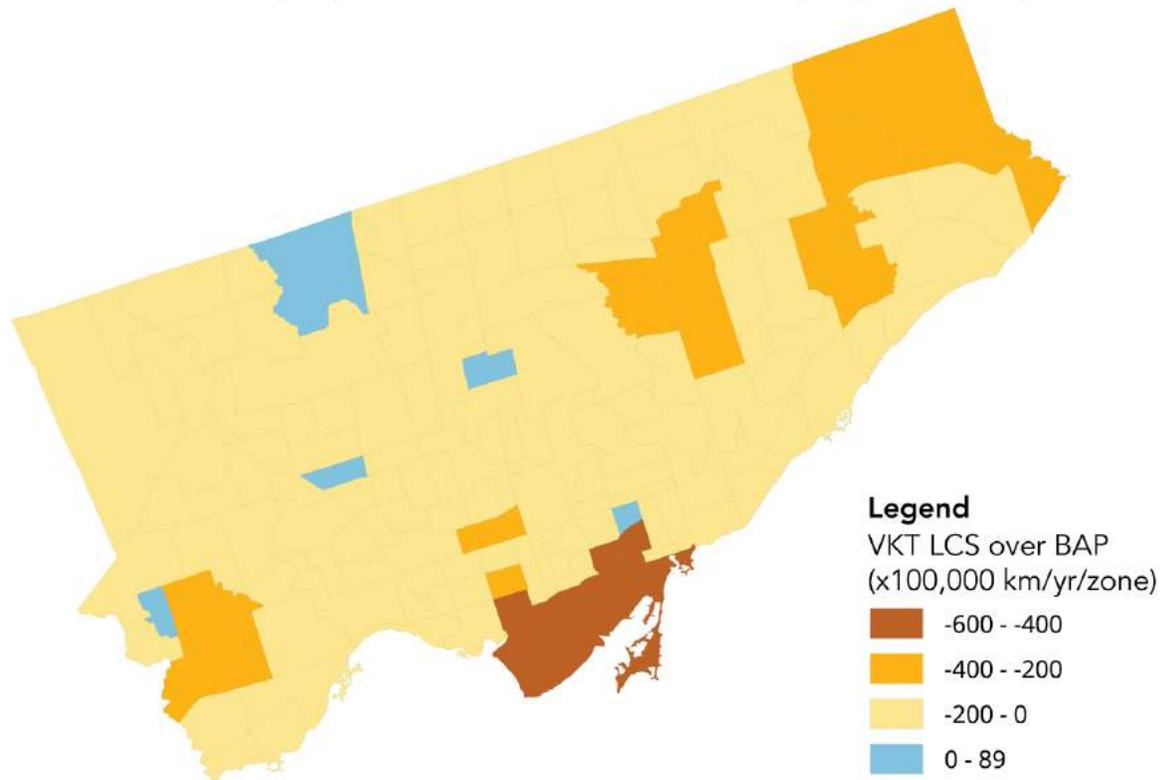
*Figure 40. Increase/decrease in VKT by zone of LCS over BAP.*

Two factors result in reduced noise in the LCS. Firstly, there is less driving, as illustrated by Figure 40, particularly in the downtown core. Secondly, electric motors are quieter than internal combustion engines and the noise associated with electric vehicles results from the tires and movement of the air, which increases with speed. Traffic-related noise has been associated with a number of health impacts including cardiovascular disease,[77] annoyance,[78] sleep disturbance and heart attacks.[79] The number of people impacted by noise from vehicles in the LCS will decline by up to a third as a result of the change in engine technologies.[80] However, due to the reduction in noise, there is also a potential increased risk of accidents between electric vehicles and pedestrians and cyclists. This risk is higher for individuals who are blind or

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77   Curran, J. H., Ward, H. D., Shum, M., & Davies, H. W. (2013). Reducing cardiovascular health impacts from traffic-related noise and air pollution: intervention strategies.

78   Miedema, H. M. E., & Oudshoorn, C. G. M. (2001). Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals. Environmental Health Perspectives, 109(4), 409–416.

79   De Nazelle, A., Nieuwenhuijsen, M. J., Antó, J. M., Brauer, M., Briggs, D., Braun-Fahrlander, C., … Lebret, E. (2011). Improving health through policies that promote active travel: A review of evidence to support integrated health impact assessment. Environment International, 37(4), 766–777.

80   Verheijen, E., & Jabben, J. (2010). Effect of electric cars on traffic noise and safety. RIVM Letter Report, 680300009, 2010.

visually impaired, as the "cue" of noise associated with a vehicle is reduced, but this risk can be mitigated by adding audio cues to electric vehicles.

## 6.1.4  Better access
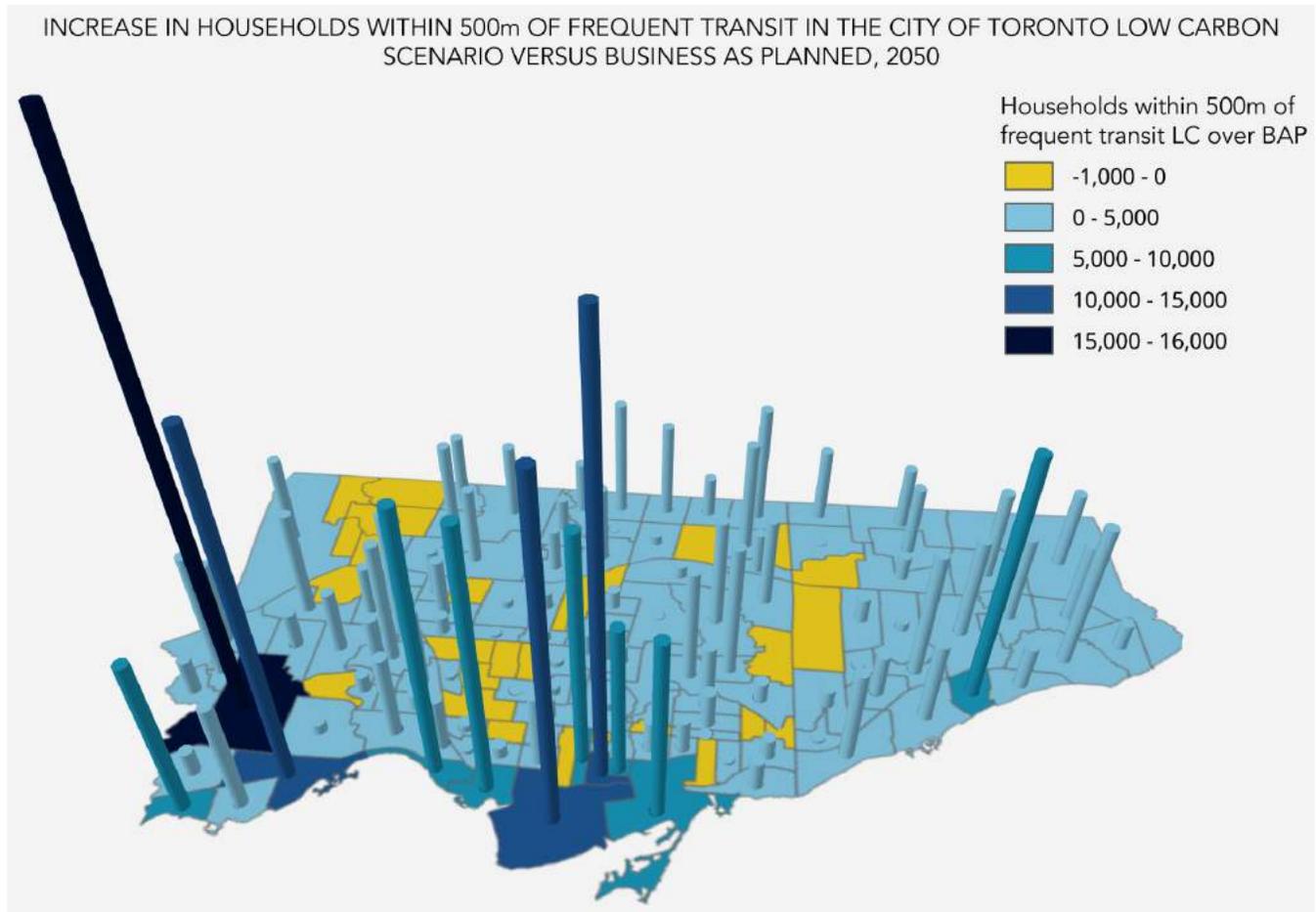


*Figure 41. Change in dwelling units within 500m of transit in the LCS over the BAP.*

Two forms of access were considered. In the first, the proximity of dwellings to transit increases in the LCS across the city relative to the BAP in 2050, as illustrated in Figure 41. Overall access to transit as a result of the LCS is greater for residents in the city, most significantly because of the introduction of new transit services and less significantly because of encouraging future growth along transit corridors.

Secondly, transport infrastructure results in the physical or psychological separation of neighbourhoods, which has been characterised as community severance.[81] In relation to transport, three common types of 'community

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81    Rode, Philipp, Graham Floater, Nikolas Thomopoulos, James Docherty, Peter Schwinger, Anjali Mahendra, and Wanli Fang. "Accessibility in Cities: Transport and Urban Form," 2014.

severance',[82] have been identified, which are reduced in the LCS relative to the BAP. First, the physical barriers designed to facilitate the uninterrupted movement of vehicles are reduced in the LCS as a result of investments in walking and cycling infrastructure. Second, psychological barriers resulting from perceptions related to traffic noise and road safety are reduced because of decreased vehicular traffic and increased walking and cycling. The third factor, in which long-term social impacts result from major construction or infrastructure projects, may actually increase with disruption that will result from the installation of new transit infrastructure and district energy in the LCS.

## 6.1.5  Enhancing social capital

Social capital is defined by the OECD as the links, shared values and understandings in society that enable individuals and groups to trust each other and work together.[83]

Actions that encourage people to walk and cycle increase the opportunity for people to make new and different connections and simply to engage with one another. The average time walking and cycling outside in 2050 in the LCS is 70 hours per year, more than three times that of the 17 hours in the Business-as-Planned Scenario.[84] "Spontaneous 'bumping into' neighbours, brief conversations, or just waving hello can help to encourage a sense of trust and a sense of connection between people and the places they live. These casual contacts can occur in stores, at neighbourhood parks, or on the sidewalk. These contacts breed a sense of familiarity and predictability that most people find comforting.[85] Putnam, who helped conceptualize social capital, has asked rhetorically if it is more desirable to have more police on the streets or for more people to know their neighbours.[86] One concrete answer to Putnam's question is that a neighbourhood with greater social capital is associated with better mental health and fewer problem behaviours amongst younger people.[87]

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82    Bradbury, A., Tomlinson, P.,Millington, A. (2007). Understanding the evolution of community severance and its consequences on mobility and social cohesion over the past century. European Transport Conference 2007, Creating a Livable Environment Seminar, Association https://doi.org/10.1073/pnas.1609244114

83    OECD. (n.d.). *OECD Insights: What is social capital?* Retrieved from http://www.ingentaconnect.com/content/oecd/16815378/2007/0 0002007/00000001/0107101ec007

84    This estimate is calculated based on a walking rate of  4 km/h and a cycling rate of 15 km/h.

85    Leyden, K. (2003). Social capital and the built environment: The importance of walkable neighbourhoods. American Journal of Public Health, 93(9), pp. 1546-1551, p. 1546

86    Putnam, R. D. (2001). *Bowling Alone: The Collapse and Revival of American Community.* Simon and Schuster.

87    McPherson, K. E., Kerr, S., McGee, E., Morgan, A., Cheater, F. M., McLean, J., & Egan, J. (2014). The association between social capital and mental health and behavioural problems in children and adolescents: an integrative systematic review. *BMC Psychology*, 2. https://doi.org/10.1186/2050-7283-2-7

## 6.1.6  Healthier buildings

RESIDENTIAL RETROFITS AND RENOVATIONS IN THE CITY OF
TORONTO LOW CARBON SCENARIO, 2016 - 2051
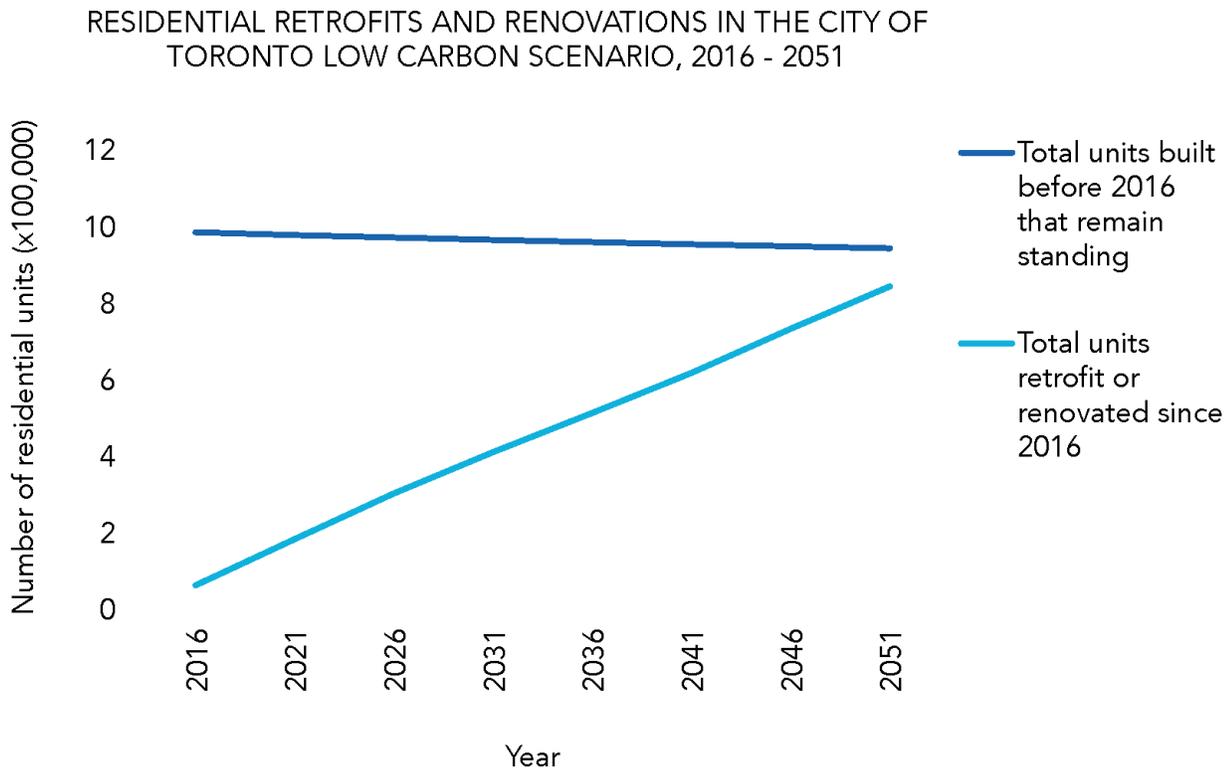


*Figure 42.  Number of units retrofit by 2050 in the LCS.*

By 2050, almost all the pre-2016 building stock is retrofit in the LCS, improving the indoor environmental quality of the building stock. As people typically spend 90% of their time indoors,[88] indoor environmental quality can have a significant impact on mental and physical health. The retrofits will address the phenomenon of 'sick building syndrome', prevalent in buildings of the 1980s and 1990s era in particular, in which occupants of a building experience acute health or comfort-related effects.[89] Additionally, the process of recommissioning will ensure that the building systems are functioning as designed and will identify and correct any issues on an ongoing basis. The improved energy performance of the buildings will also affect health by providing more comfortable indoor temperatures and reducing and stabilizing the cost of energy, which is particularly important to address fuel poverty, when individuals living on a lower income cannot be kept warm at a reasonable cost.[90]

88    U.S. Environmental Protection Agency (EPA). 1989. Report to Congress on Indoor Air Quality — Vol. II: Assessment and Control of Indoor Air Pollution. EPA/400/1-89/001C. Washington, D.C.: US EPA.

89    Joshi, S. M. (2008). The sick building syndrome. *Indian Journal of Occupational and Environmental Medicine*, 12(2), 61–64. https://doi.org/10.4103/0019-5278.43262.   Available at tinyurl.com/CCN-2013-R017E.

90    Milner, J., Davies, M., & Wilkinson, P. (2012). Urban energy, carbon management (low carbon cities) and co-benefits for human health. *Current Opinion in Environmental Sustainability*, 4(4), 398–404.

## 6.2 An investment in economic prosperity

Economic prosperity is defined as the capability to flourish, a definition developed by the UK Sustainable Development Commission.[91] In articulating this definition, the authors cite broad questions posed by the economist Amartya Sen about how people are able to function: Are they well nourished? Are they free from avoidable morbidity? Do they live long? Can they take part in the life of the community? Can they appear in public without shame and without feeling disgraced? Can they find worthwhile jobs? Can they keep themselves warm? Can they use their school education? Can they visit friends and relations if they choose?[92]

The notion of the capability to flourish as a definition of economic prosperity is consistent with the intention of key City documents such as *One Toronto* and *TO Prosperity: Toronto Poverty Reduction Strategy* and is complementary to the categories on health and social equity discussed elsewhere in this report. As the UK Sustainable Development Commission argued, this definition is also consistent with the intention of preventing dangerous levels of climate change.

In considering potential co-benefits and co-harms of efforts to reduce GHG emissions, the aspects of economic prosperity which will be considered include job opportunities, household incomes, investment opportunities, municipal finance, reputation and the energy footprint.

### 6.2.1 New job opportunities

In general, the transition to a low carbon economy is expected to have four categories of impacts on labour markets. First, additional jobs will be created in emerging sectors. Second, some employment will be shifted, for example from fossil fuels to renewables. Third, certain jobs will be eliminated, such as vehicle mechanics who specialize in gasoline motors. Fourth, many existing jobs will be transformed and redefined.[93]

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91    Jackson, T. (2009). p.21 *Prosperity without growth: economics for a finite planet.* London ; Sterling, VA: Earthscan.

92    Nussbaum, M., Sen, A., & Research, W. I. for D. E. (1993). *The Quality of Life.* Oxford University Press.

93    Martinez-Fernandez, C., Hinojosa, C., & Miranda, G. (2010). Green jobs and skills: the local labour market implications of addressing climate change. *Working Document*, OECD. Retrieved from http://www.oecd.org/regional/leed/44683169.pdf

PERSON-YEARS OF EMPLOYMENT ADDED IN THE CITY OF TORONTO
LCS OVER BAP, 2017 - 2050

**Emissions reduction actions**

- Transit stock
- District energy
- Residential vehicles
- High efficiency residential buildings
- Residential retrofits
- Decentralised energy
- Commercial vehicles
- High efficiency non-residential buildings
- Commercial retrofits
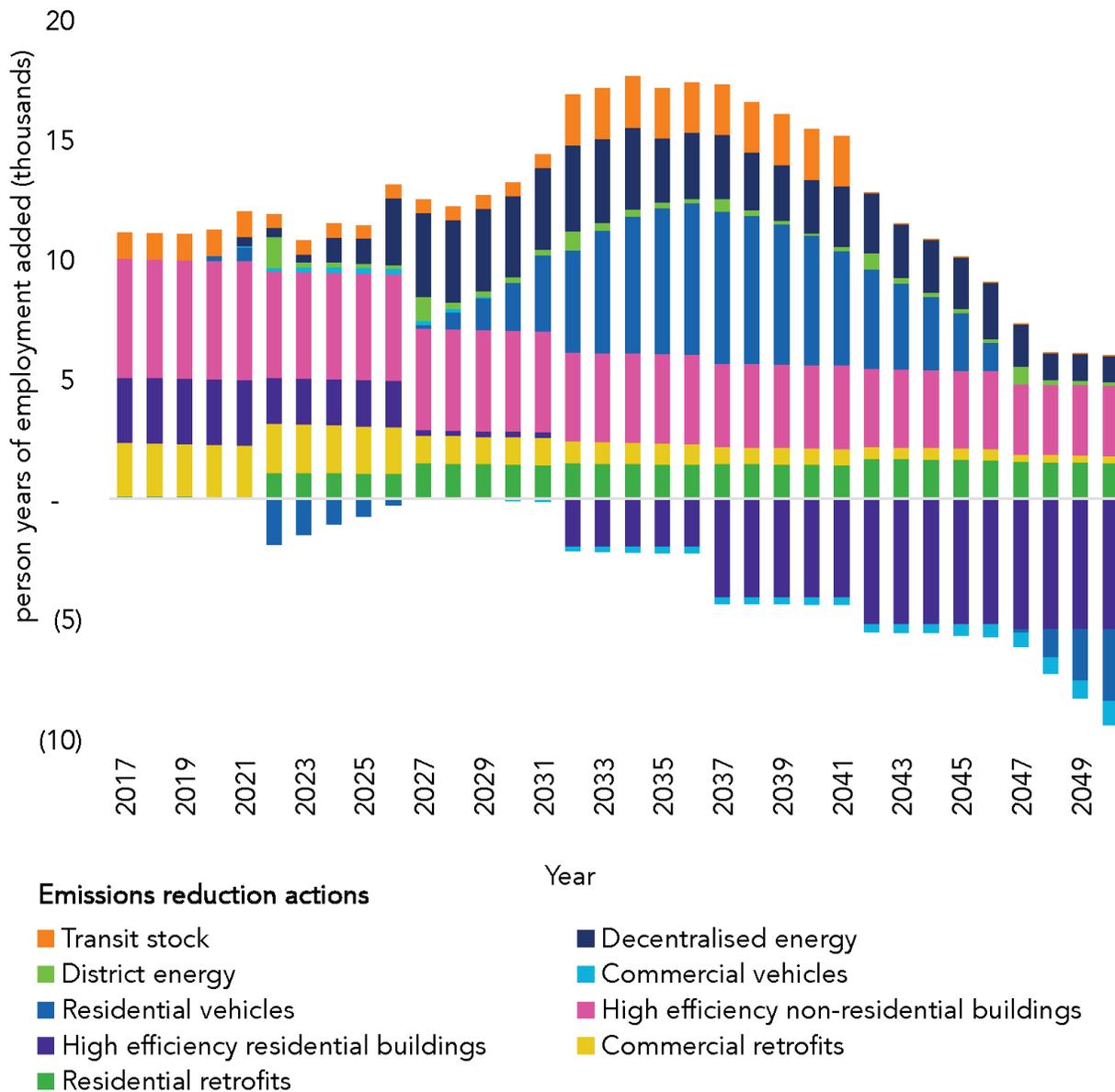
*Figure 43. Additional person-years of employment associated with the LCS*

Figure 43 uses employment multipliers to illustrate the effect of projected investments in the LCS on person-years of employment, over and above the jobs associated with the BAP scenario. Over 327,000 net person years of employment are added, an average of 10,000 person years of employment per year. These person-years of employment do not necessarily represent new jobs, as some jobs may be displaced or eliminated, but they represent new employment opportunities within the city, if appropriate policies are put in place.

In some sectors person-years of employment decline, as illustrated by bars that fall below 0. The primary source of this decline is a result of autonomous vehicles, which decreases the number of vehicles on the road, and in new construction, reflecting a decrease in the cost of high performance buildings as experience with this type of construction grows. Because jobs are a

function of the investment and the total investment declines relative to the BAP scenario, the number of jobs also declines in the building sector. Similarly, in the last few years of the scenario, the capital cost of vehicles is less than in the BAP scenario, reflecting the projected decreased cost of electric vehicle production. The result of the decreased capital costs is that the number of jobs for vehicle production is less than in the BAP.[94]

## 6.2.2 Cost savings for households

HOUSEHOLD ENERGY EXPENDITURES IN THE CITY OF TORONTO LOW CARBON SCENARIO (LCS) VERSUS BUSINESS AS PLANNED (BAP) SCENARIO, 2050



**Legend**
Energy expenditures ($ per household), LCS over BAP

- -500 - -375
- -375 - -250
- -250 - -125
- -125 - 0
- 0 - 125
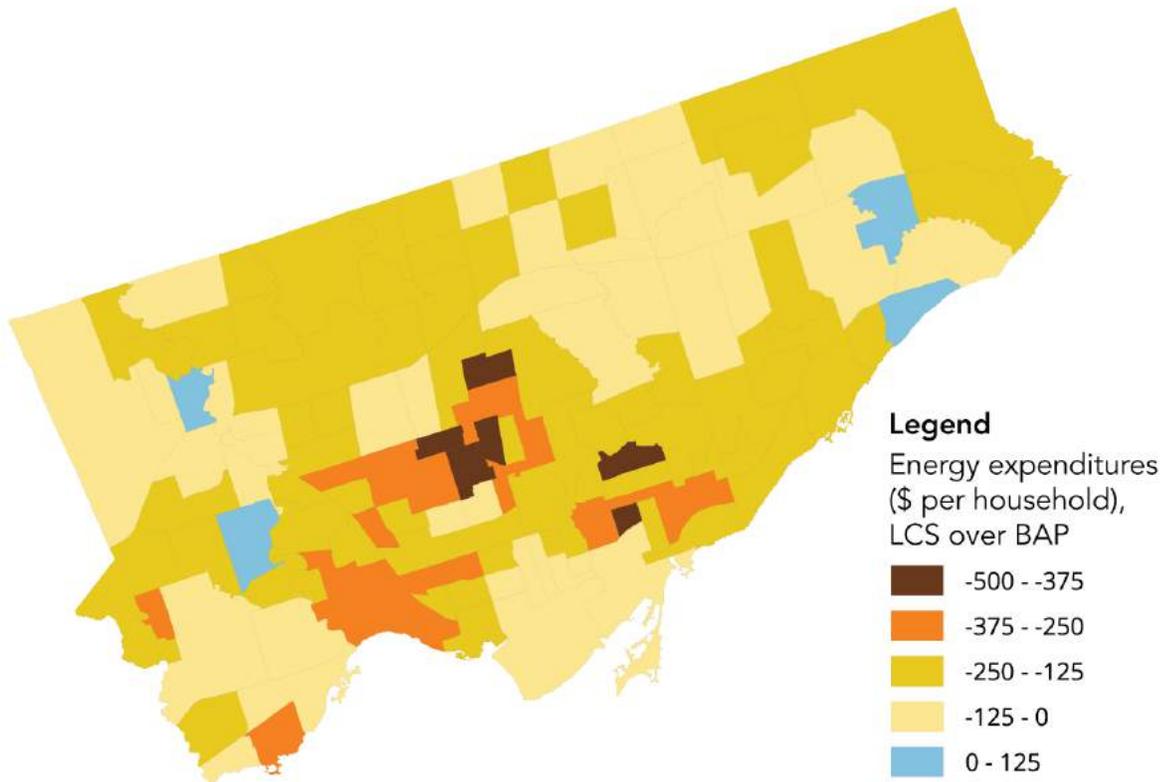
*Figure 44. Change in household energy expenditures of LCS over BAP.*

Measures to reduce GHG emissions result in reduced household energy costs, as energy requirements for electricity and heating and cooling dwellings decline, illustrated in Figure 44. There are four neighbourhoods, in blue, that experience increases in costs. Significant efficiency gains are partially offset by the switch from cheaper natural gas to costlier electricity for heating in buildings.

For dwellings in six neighbourhoods, the savings are between $375 and $500

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94    Productivity per person is assumed to be constant over the time period considered and no assumptions are made around increasing automation.

per year for heating, cooling and electricity, as indicated in Figure 44. Due to extensive district energy and the use of renewable energy, these costs are also resilient against fluctuations in global commodities.

Another consideration is the potential for a rebound effect, whereby households use the financial savings resulting from energy efficiency gains to access services that use more energy and increase GHG emissions. The additional financial resources may, however, increase wellbeing, particularly for low-income households.

## 2.1.1  Stimulating investment
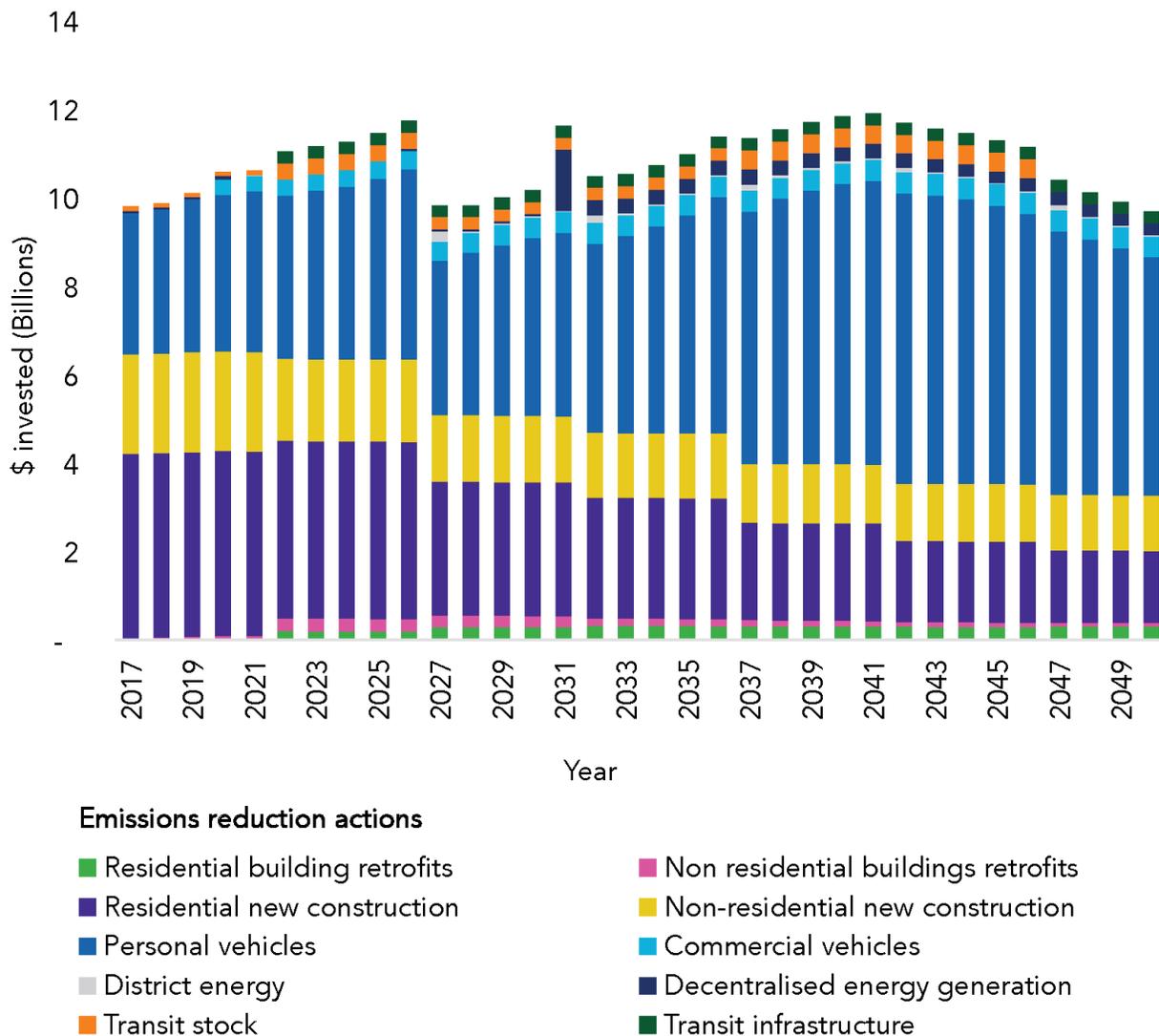


Figure 45. Total investment in the LCS

Cities have policy levers that can unlock major economic opportunities,

which can lead to new opportunities for for-profit and social enterprises both in the city and as exports to economies around the world. The LCS unlocks investment opportunities in buildings, the energy system, the transportation system and in solid waste.

Total investment by theme is illustrated in Figure 45. The pattern is a function of the five year steps that the model uses to represent various stocks. Total annual investments range between $10 and $12 billion per year over the period but much of this investment occurs with the normal turnover of stocks, irrespective of the low carbon pathway. For example, people will purchase cars, irrespective of whether they are electric or not, requiring capital investment in cars in both scenarios. The incremental difference between the LCS and the BAP scenario represents the total additional investment required to finance the additional GHG reductions to 80% reduction by 2050. The annual incremental investment peaks at just over $6 billion in one year and at a 3% discounting rate, the cumulative incremental investment of the LCS over the BAP is $60 billion in 2017$, using a 3% discounting rate. This investment includes significant opportunities for existing and future businesses in all sectors and already new markets and investment opportunities are emerging. For example, the rapid growth of green and climate bonds[95] gives rise to new financial sectors, an opportunity for the City of Toronto, under the LCS.

An ancillary benefit of the LCS is the stimulation of risk mitigation within the private sector. For example, using global fossil reserves is incompatible with emissions reductions targets.[96] Enterprises or investors with ownership of these reserves face a risk that these assets may be stranded. Actions to reduce GHG emissions help to refocus the economy on low carbon solutions whereas delaying policies on climate action increases the risk of stranded assets.[97]

95    Climate Bonds Initiative. (2016). *Bonds and climate change: The state of the market in 2016.* Retrieved from https://www.climatebonds.net/files/files/report

96    Carbon Tracker Initiative. (2011). Unburnable carbon: Are the world's financial markets carrying a carbon bubble? Retrieved from http://www.carbontracker.org/wp-content/uploads/2014/09/Unburnable-Carbon-Full-rev2-1.pdf

97    Nelson, D., Herve-Mignucci, M., Goggins, A, Szambelan, S., Vladeck, T., & Zuckerman, J. (2014). Moving to a low-carbon economy: The impact of policy pathways on fossil fuel asset values. Retrieved from https://climatepolicyinitiative.org/wp-content/uploads/2014/10/Moving-to-a-Low-Carbon-Economy-The-Impacts-of-Policy-Pathways-on-Fossil-Fuel-Asset-Values.pdf

CHANGE IN YEARLY COMMERCIAL/INDUSTRIAL ENERGY EXPENDITURES PER m2 OF FLOORSPACE IN THE CITY OF TORONTO LOW CARBON SCENARIO (LCS) OVER BUSINESS AS PLANNED (BAP), 2050

**Legend**
Expenditures per m2 floor area, LCS over BAP

- -15 - 0
- 0 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 263
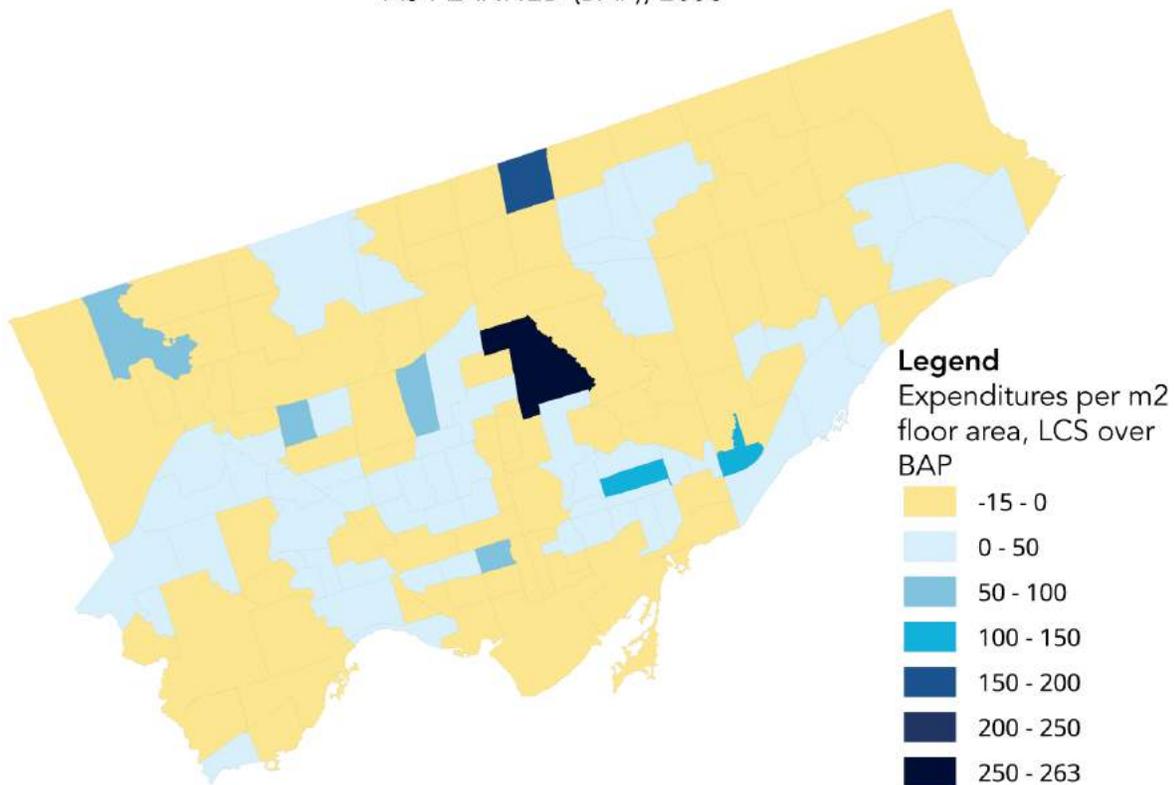
*Figure 46. Impact on energy costs for commercial/industrial floor space of LCS over BAP by zone.*

In addition to new investment opportunities, the LCS results in lower operating costs for businesses as energy costs per floor space in nearly every neighbourhood across the city. Fuel switching from cheaper natural gas to more expensive electricity does result in increases in a small number of neighbourhoods.

## 2.1.2  Municipal finances

Figure 47 illustrates the direct costs and savings associated with the LCS over the BAP for the City of Toronto as a municipality. Savings are represented as positive and costs are negative. Capital costs include electrification of the transit fleet, the addition of cycling infrastructure and additional transit infrastructure. Transit revenues decline over the BAP because some transit trips shift to walking and cycling and others shift to autonomous vehicles. As the transit fleet electrifies, there are some initial costs due to the higher per unit cost of electricity relative to diesel, but increased efficiencies result in fuel cost savings later on. Additional savings result from the avoided cost of carbon result from reduced emissions due to electrification. At a 3% discount rate, this investment achieves a net present value of -$6 billion in 2016$, primarily as a result of new transit stock and operating costs.

# IMPACTS OF EMISSIONS REDUCTIONS ACTIONS ON MUNICIPAL REVENUES AND COSTS FOR THE CITY OF TORONTO LCS, 2017 - 2050



**Revenue / cost category**

■ Municipal capital costs ■ Municipal fuel ■ Municipal emissions ■ Transit revenues
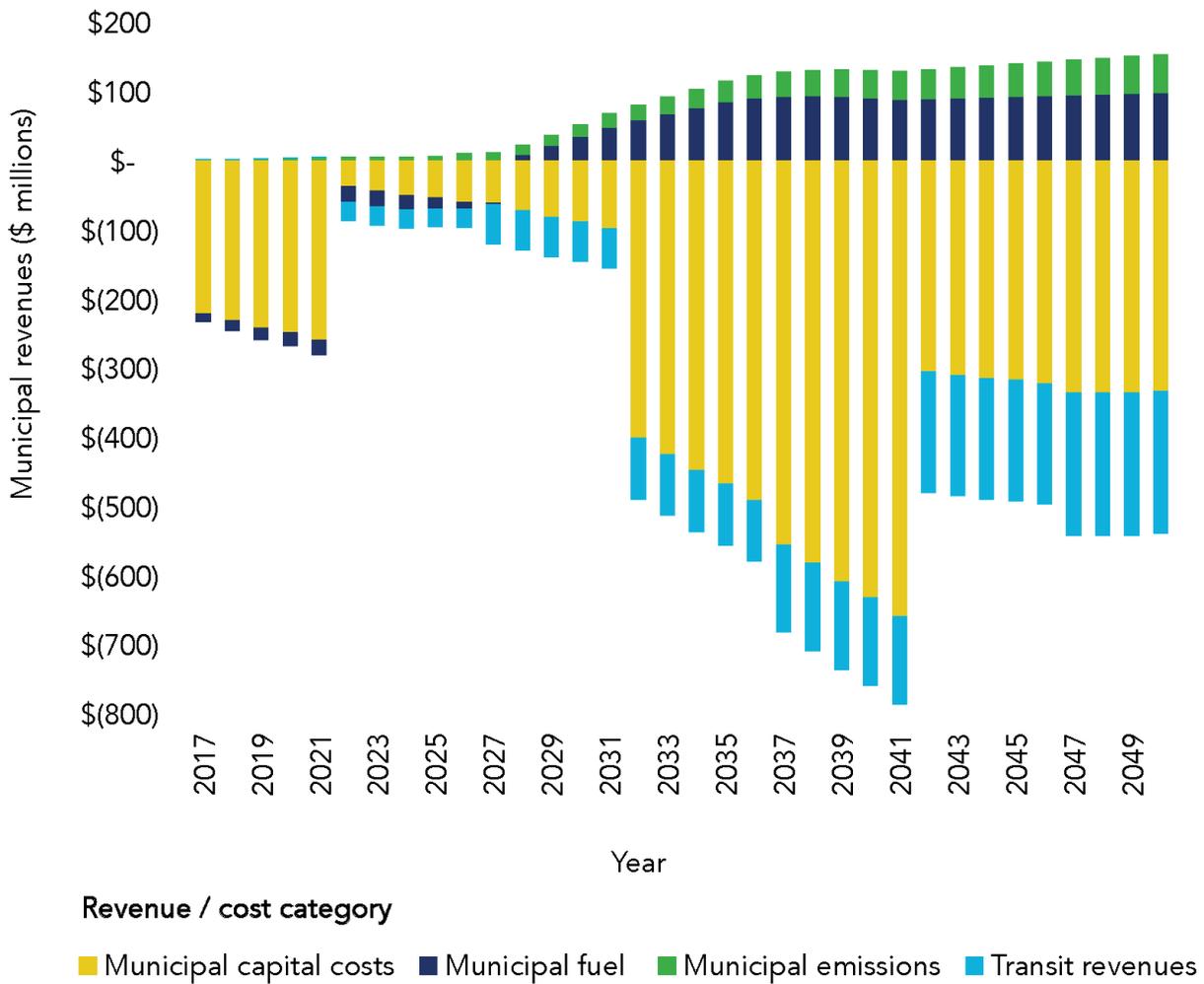
*Figure 47. Financial implications for municipal expenditures*

## 6.2.3  Stimulating innovation

Actions that reduce GHG emissions will stimulate innovation as enterprises reposition themselves and invest in research and development to provide new services, business models and markets. This process triggers technology diffusion, adaptation and experimentation in the public and private sectors.

Innovation has a powerful effect on productivity and economic growth as well as creating opportunities to advance well-being. There are the obvious technological innovations associated with the LCS including hydrogen fuel cells, electric vehicles, batteries, solar photovoltaics, and others. There are also social innovations such as energy cooperatives or car sharing, which attract less attention, but provide a wide range of benefits. Other examples will disrupt major established energy delivery systems, such as microgrids, decentralised generation and storage, and advanced district energy. District

energy, passive houses and microgrids are examples of innovating systems, rather than innovating specific technologies. These examples are but a few of how low carbon innovation is rapidly transforming society; actions to reduce GHG emissions can support and encourage these innovations and innovators.[98]

On the negative side of the equation, innovation can contribute to or enhance inequality as some low-productivity jobs remain.[99] Previous episodes of innovation-led structural change, however, indicate that this process can result in job creation, productivity increases and growth, by creating new consumers rather than competing with existing consumers, providing a simpler offering and applying new business models. In the case of the climate economy, an example is providing electric vehicles as a service.

### 2.1.3  Reputation

Branding and image are potential co-benefits of climate action. The Brand Finance company valued the City of Vancouver's brand at $31 billion, and found that it was associated with the environment, 'green' living and environmental leadership, ahead of other cities including San Francisco, Singapore, Sydney, Shanghai and Hong Kong.[100] Various rankings including the Sustainable Cities Index,[101] the Green City Index[102] and RepTrak[103] contribute to brand positioning with respect to climate action and sustainability. The ambition of the LCS would significantly enhance the city's standing internationally as a beacon of action on climate change and a clean economy.

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98   Willis, R., Webb, M., & Wilsdon, J. (2007). The Disrupters: Lessons for low-carbon innovation from the new wave of environmental pioneers. Retrieved from http://sro.sussex.ac.uk/47867

99   Fankhaeser, S., Sehlleier, F., & Stern, N. (2008). Climate change, innovation and jobs. Climate Policy, 8(4), 421–429.

100  City of Vancouver. (n.d.). Written evidence of the City of Vancouver- Appendix 82. Retrieved from http://vancouver.ca/files/cov/Evidence-Edgar-Baum-Vancouver-brand-valuation.pdf

101   Arcadis. (n.d.). Sustainable Cities Index 2016. Retrieved November 11, 2016, from https://www.arcadis.com/en/global/our-perspectives/sustainable-cities-index-2016/

102  Economist Intelligence Unit. (2011). US and Canada green city index: Assessing the environmental performance of 27 major US and Canadian cities. Retrieved from http://www.siemens.com/entry/cc/features/greencityindex_international/all/en/pdf/report_northamerica_en.pdf

103  City RepTrak 2015- Most Reputable Cities. (n.d.). Retrieved November 11, 2016, from https://www.reputationinstitute.com/Resources/Registered/PDF-Resources/City-RepTrak-Report-2015.aspx

## 2.1.4  Toronto's energy footprint

REDUCTION IN LAND AREA ASSOCIATED WITH ENERGY GENERATION
IN THE CITY OF TORONTO FROM LCS TO BAP,  2050



Reduction in land footprint associated with energy generation of LCS
compared with BAP (km2)
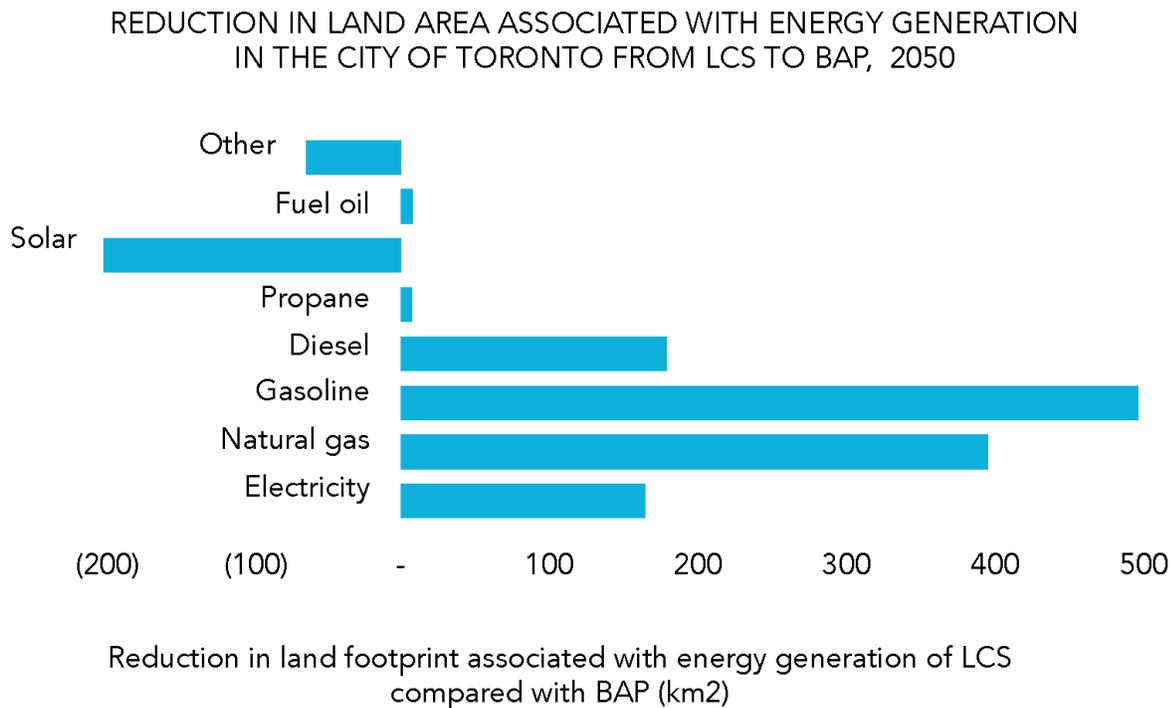
*Figure 48. Reduced energy sprawl as a result of the low carbon scenario*

The co-benefits and co-harms of actions to reduce GHG emissions on environmental capital are complex and seldom considered, as illustrated by the land footprint associated with providing energy, which one paper describes as energy sprawl.[104] While GHG emissions are a threat to biodiversity and ecosystems, as well as human well-being, all forms of energy generation, including renewables have a spatial footprint, requiring a certain area of land, mostly beyond city boundaries, and that land could otherwise be used to maintain biodiversity or for agriculture or forestry. Through reduced fossil fuel consumption and energy efficiency gains, the LCS results in a reduced energy footprint of approximately 1,048 km2, an area more than one and half times as large as the City, illustrated in Figure 48. The energy footprint is a beneficial impact, but a co-harm which was not analysed is the increased demand for construction materials such as wood and concrete that would be required for the program of retrofits included in the LCS.

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104  McDonald, R. I., Fargione, J., Kiesecker, J., Miller, W. M., & Powell, J. (2009). Energy sprawl or energy efficiency: Climate policy impacts on natural habitat for the United States of America. PLoS ONE, 4(8), e6802. https://doi.org/10.1371/journal. pone.0006802

## 6.3 Enhancing social equity

The City of Toronto defines equity as distributing opportunities and resources equally, accommodating different needs and removing barriers in order to level out unfair and unjust outcomes so that individuals can benefit equally. Social equity implies fair access to livelihood, education, and resources; full participation in the political and cultural life of the community; and self-determination in meeting fundamental needs.[105]

Not all individuals or all communities are equally affected by climate change.[106] People living in different geographies, with different capacities, and with different jobs will experience climate change effects differently. Climate change vulnerability is the degree to which people and places are at risk from the impacts of climate change, and their ability to cope with those impacts.[107] Climate change resilience is essentially the flip side of vulnerability, "the ability to survive, recover from, and even thrive in changing climatic conditions."[108] Some aspects of resilience include physical and psychological health, social and economic equity and well-being, availability of information and effective risk communication, integration of governmental and non-governmental organizations, and social capital and connectedness.[109]

Climate change amplifies vulnerability and hampers adaptive capacity, especially for persons with low-income, Aboriginal Peoples, LGBTQ2S communities, undocumented individuals, immigrants and refugees, diverse women, seniors, children, persons with disabilities, and racialized groups. These groups often lack power as well as access to resources, adequate urban services, and reliable infrastructure. Equity-seeking groups both start off from a position of disadvantage that make them more vulnerable to the impacts of climate change and lack the power and resources to adapt and respond to climate change. For example, poverty and marginalization not only reduces people's capacity to absorb rising food, water, and energy prices, but it also limits their ability to invest in resources and prepare for the impacts of climate change. Following a disaster, it is much harder for low-income and marginalised communities to rebuild, as these groups are less likely to have the social capital and resources to effectively advocate to have their needs met.

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105  Summers, J. K., & Smith, L. M. (2014). The role of social and intergenerational equity in making changes in human well-being sustainable. Ambio, 43(6), 718–728. https://doi.org/10.1007/s13280-013-0483-6

106  Rudolph, L., Gould, S., and Berko, J. "Climate Change, Health and Equity: Opportunities for Action." Oakland, CA: Public Health Institute, 2015. https://www.phi.org/uploads/application/files/h7fjouo1i38v3tu427p9s9kcmhs3oxsi7tsg1fovh3yesd5hxu.pdf.

107  IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Field CB, Barros VR, Dokken DJ, et al., eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014.

108  Asian Development Bank. Urban Climate Change Resilience: A Synopsis. 2014. Manila, Philippines. Available at http://www.adb.org/sites/default/files/ publication/149164/urban-climate-change-resiliencesynopsis.pdf

109  U.S. Environmental Protection Agency. Reducing urban heat islands: compendium of strategies: trees and vegetation. US EPA, Climate Protection Partnership Division, Office of Atmospheric Programs. 2008. Available at: https://www.epa.gov/sites/production/files/2014-06/documents/activitiescompendium.pdf

## 2.1.5  Poverty

2014 LOW INCOME POPULATION AND ZONES SHOWING AN INCREASE IN HOUSEHOLD
ENERGY EXPENDITURES FOR THE CITY OF TORONTO LOW CARBON SCENARIO, 2050
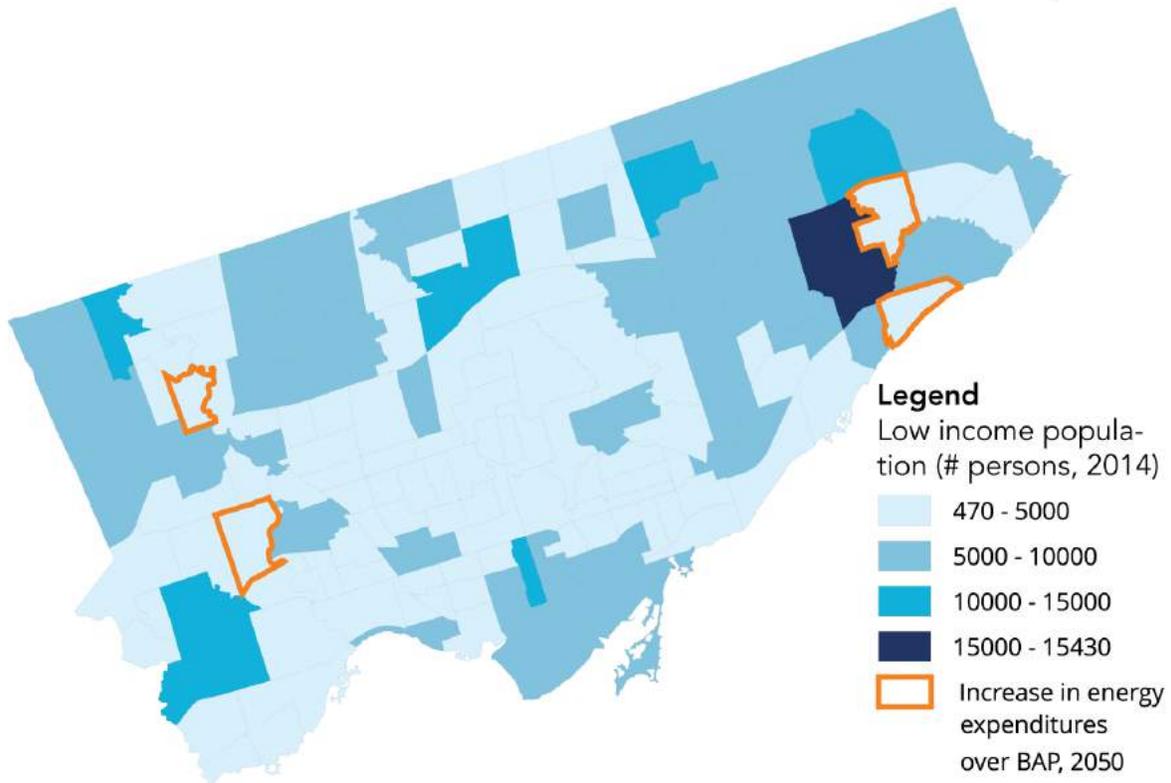


*Figure 49. Impact of energy cost increases/decreases for housing of the LCS over BAP in vulnerable neighbourhoods.*

Figure 49 considers the impact of energy costs associated with housing in the LCS against neighbourhoods with low income populations. All of the neighbourhoods with a concentration of low income people will experience a decline in building related energy costs in 2050 as compared with the BAP scenario, however it is dependent on policies to ensure that the residents rather than the building owners receive the benefits of these savings. Because almost all the building stock has been retrofit, the quality of housing will improve in the LCS, and if appropriate policies are introduced energy prices will not be subject to the global fluctuations, resulting in greater price security.

Dense, well-managed urban development and the provision of accessible, affordable public transport can have a positive direct effect on low income and marginalised groups by increasing their ability to access goods, services, and economic opportunities, and by providing opportunities for participation in the supply of transport-related infrastructure and services.

In addition to the impacts of the LCS on energy costs, low income individuals are often marginalized from opportunities to reduce GHG emissions, which

typically have a cost, even though they are as eager to be part of the solution as others. Consideration of programs and policies which facilitate the participation of low-income people and other marginalized groups is critical to ensuring an equitable approach.

## 2.1.6  A city for the seniors

The increased access to public transportation and autonomous vehicles in the LCS can overcome barriers for those who cannot drive or who cannot afford an automobile – low-income people, some seniors, as well as some people with disabilities.[110]

The increased intensification in the LCS also benefits seniors, resulting in more active lifestyles, decreased respiratory issues and decreased use of medication due to lower ozone levels and decreased air pollution.[111] There can also be mental and social capital improvements that come with decreased isolation and strengthened community networks.

The built environment in the LCS includes major improvements in walking and cycling infrastructure, encouraging physical fitness and exercise and increasing overall health among seniors. Oxygen uptake and flexibility both increase with physical activity,[112] which also increases psychological and spiritual health. According to one author, "physical activity in the natural environment not only aids an increased life-span, greater well-being, fewer symptoms of depression, lower rates of smoking and substance misuse, but also increases ability to function better at work and home.[113]

Retrofitting buildings for energy efficiency may reduce the impact of heat on seniors, a high-risk population in terms of developing severe heat stroke, heat exhaustion, fainting, swelling or heat cramps during a heat wave.

## 2.1.7  A child friendly city

The two most significant immediate benefits of the LCS are increased accessibility and reduced air pollution. As with seniors, children are reliant on walking, cycling and transit for access to destinations. In the LCS, destinations are more accessible to dwellings as a result of enhanced intensification, and walking, cycling and transit are more viable. In addition, autonomous vehicles provide a new option for transport for children.

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110   Jackson, R. and C. Kochtitzky. (2010). Creating a Healthy Environment: The Impact of the Environment on Public Health. Centers for Disease Control and Prevention. Sprawl Watch Clearinghouse Monograph Series.

111   Frumkin, H. (2002). Urban sprawl and public health. Public Health Reports, 117(3), 201–217.

112   Morris, N. (2003). Health, Well-being and Open Space. OPENspace: the Research Centre for Inclusive Access to Outdoor Environments. Edinburgh College of Art and Heriot-Watt University

113   ibid.

Air pollution is a particular concern for children as their immune system and lungs are not fully developed when exposure begins and children tend to spend more time outside increasing exposure to pollutants from the combustion of fossil fuels. The reduced air pollution associated with the LCS will therefore result in proportionately higher benefits for children, particularly as related to bronchitis and chronic cough.[114]

## 6.3.1  For future generations

Climate change represents a burden on future generations and the complexity of the climatic system means that these impacts are difficult to anticipate. The burden of action increases the longer action is delayed. In 2015, twenty-one youth from across the United States filed a landmark constitutional climate change lawsuit against the federal government in the U.S. District Court for the District of Oregon. The youth successfully asserted that, in causing climate change, the federal government violated the youngest generation's constitutional rights to life, liberty, property, as well as failed to protect essential public trust resources.[115]

The social cost of carbon (SCC) has been used in regulatory processes in Canada and the US to reflect the impacts of climate change on society. The SCC attempts to add up the quantifiable costs and benefits of a tonne of carbon dioxide. While the estimates of SCC are highly uncertain, it is one of the best ways to reflect future damages to ensure that decision-making which has implications for future emissions accounts for those implications.

The SCC includes assumptions around future conditions including population size, economic growth, rate of climate change and the impact of climate change on those conditions, drawing on the results of integrated assessment models. The discount rate is a significant assumption within the models. Discounting reflects the idea that people would rather have $100 now than $100 in ten years. From an ethical perspective, a higher discount rate indicates that future generations are worth less than current generations; for this reason the Stern Review[116] recommended a discount rate of 1.4%, well below traditional discount rates.  As Stern pointed out in a subsequent article "A 2% pure-time discount rate means that the life of someone born 35 years from now (with given consumption patterns) is deemed half as valuable as that of someone born now (with the same patterns)".[117]  The Government of Canada recommends 3% in circumstances where environmental and human

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114   Schwartz, J. (2004). Air pollution and children's health. Pediatrics, 113(4 Suppl), 1037–1043.

115   Our Children's Trust. (2016). Landmark US federal climate lawsuit. Retrieved November 14, 2016, from https://www.ourchildrenstrust.org/us/federal-lawsuit/

116   Stern, N. (2006). *The Stern review on the economic effects of climate change*. Cambridge University Press.

117   Stern, N. (2015). Economic development, climate and values: making policy. *Proc. R. Soc. B*, 282(1812), 20150820. https://doi.org/10.1098/rspb.2015.0820

health impacts are involved.[118]

This analysis presents the results of the SCC both for remaining emissions and avoided emissions associated with the LCS. Avoided emissions are defined as the emissions that would have been released had the LCS not been implemented. In addition, the Government of Canada reports on estimated damage associated with lower probability, high-cost events, again using a 3% discounting rate. This cost reflects less likely impacts of increased temperatures that result in greater damage, as described within the 95th percentile of the SCC frequency distribution.

*Table 9. Updated Canadian SCC estimates (in C$ 2012, discounted at 3%)*

|       | CENTRAL | 95TH PERCENTILE |
|-------|---------|-----------------|
| 2016  | 40.7    | 167             |
| 2020  | 45.1    | 190.7           |
| 2025  | 49.8    | 213.3           |
| 2030  | 54.5    | 235.8           |
| 2035  | 59.6    | 258.9           |
| 2040  | 64.7    | 281.9           |
| 2045  | 69.7    | 300.9           |
| 2050  | 74.8    | 319.8           |

The results of the SCC both for remaining emissions and avoided emissions associated with the BAP and Low Carbon scenarios are illustrated in Figure 50 and Figure 51.

118  Environment and Climate Change Canada. (2016). Technical update to Environment and Climate Change Canada's social cost of greenhouse gas estimates. Retrieved from http://ec.gc.ca/cc/BE705779-0495-4C53-BC29-6A055C7542B7/Technical%20 Update%20to%20Environment%20and%20Climate%20Change%20Canadas%20Social%20Cost%2

CUMULATIVE SOCIAL COST OF CARBON UNDER DIFFERENT
EMISSIONS SCENARIOS FOR THE CITY OF TORONTO AT A 3%
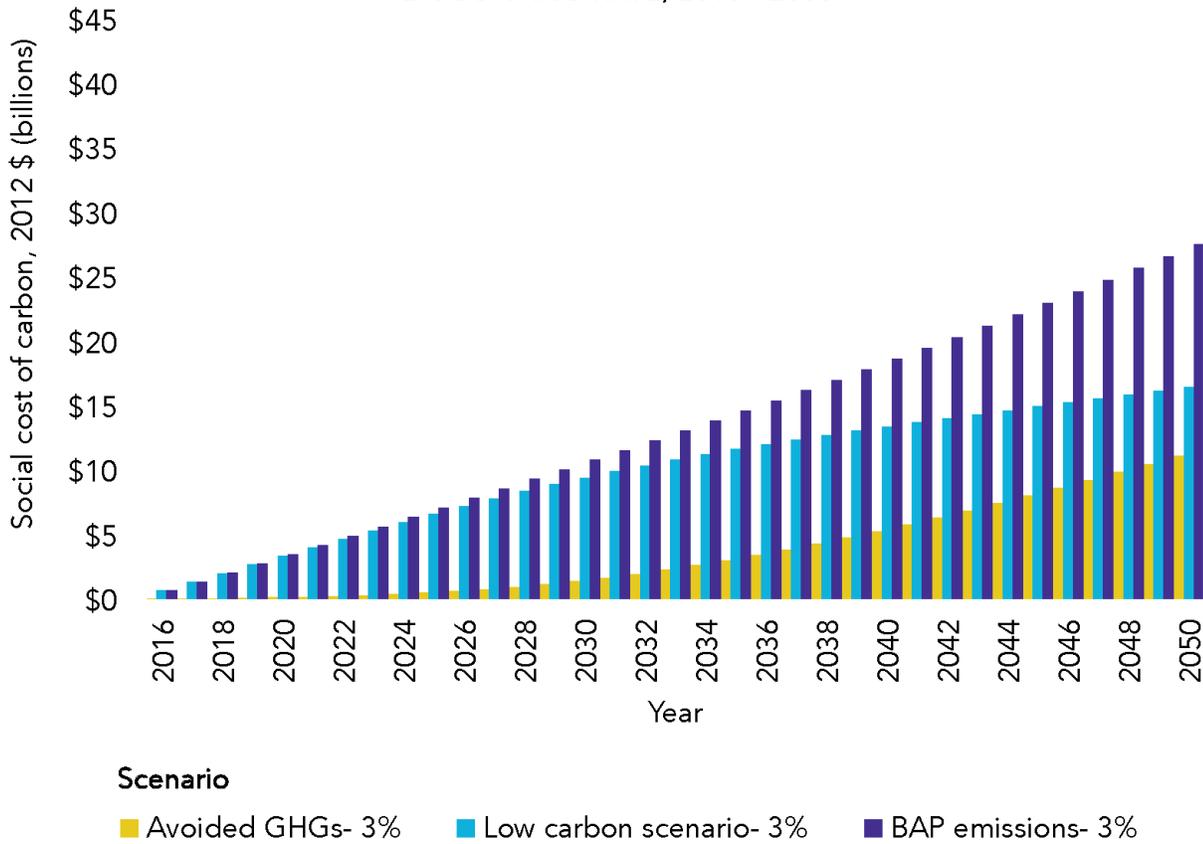DISOUNTING RATE, 2016 - 2050



Figure 50. Global[119] social cost of carbon, in $2012 cumulative at a 3%
discounting rate

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119   The "social cost of carbon' was prefaced with the word 'global' to clarify that the impacts represented by the social cost of
      carbon will be experienced by people around the world.

CUMULATIVE SOCIAL COST OF CARBON UNDER DIFFERENT EMISSIONS SCENARIOS FOR THE CITY OF TORONTO AT A 3% DISCOUNTING RATE, 95TH PERCENTILE, 2016 - 2050

**Scenario**

- Avoided GHGs- 95th percentile
- Low carbon scenario- 95th percentile
- BAP emissions- 95th percentile
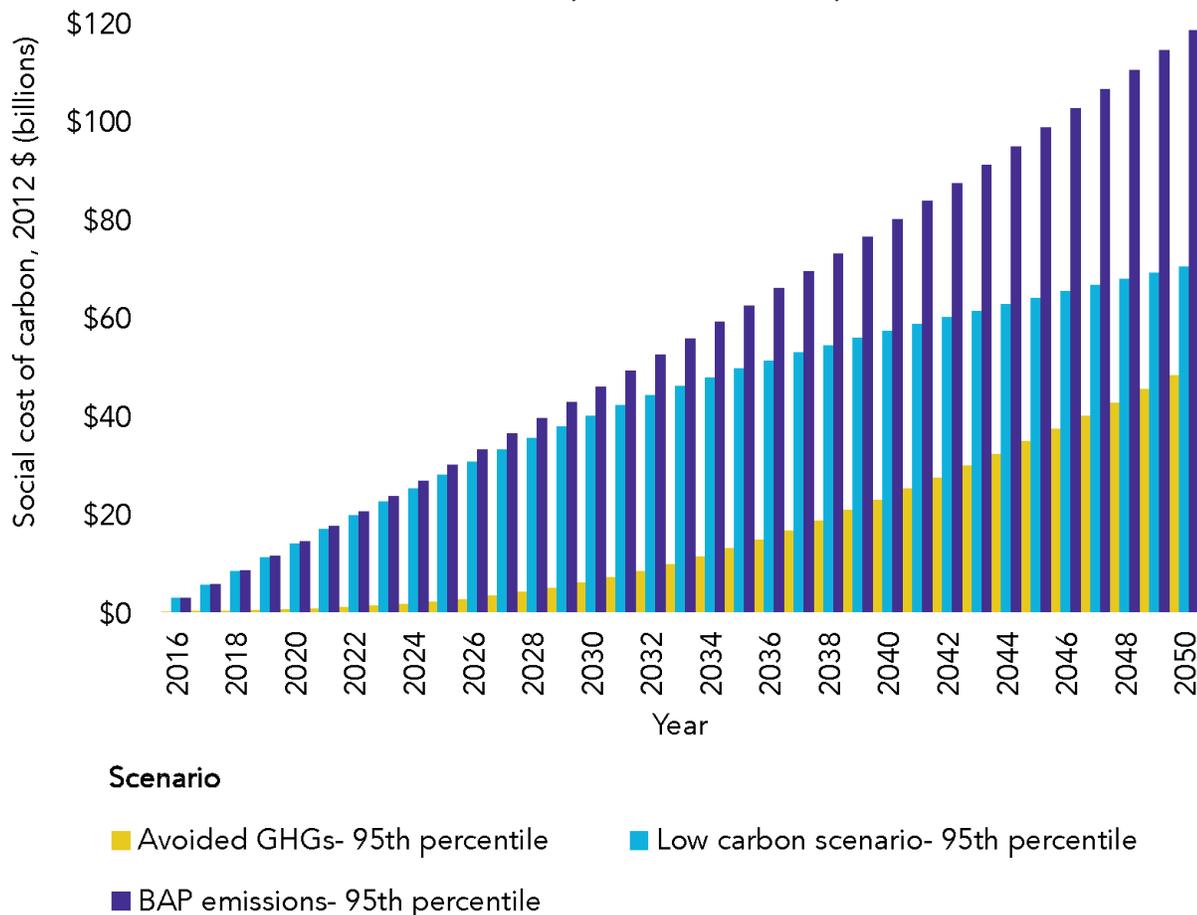
*Figure 51. Global social cost of carbon, in $2012 cumulative at a 3% discounting rate, 95th percentile*

The cumulative SCC resulting from the BAP between 2016 and 2050 are $27.5 billion and the LCS are $16.4 billion. The value of the avoided emissions, as represented by the SCC, is $11.1 billion in 2012 dollars. Under the 95th percentile category, the cost of climate change is $118 billion in the BAP and $70 billion in the LCS and the value of the avoided emissions as a results of LCS is $48 billion.

In the United States, the SCC has been used as a factor in cost benefit analysis 69 final and 80 current regulations, resulting in estimated benefits of greater than $1 trillion,[120] and the Government of Canada has used the SCC in all regulatory impact assessments that impact GHG emissions since 2011.

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120   Nordhaus, W. D. (2017). Revisiting the social cost of carbon. *Proceedings of the National Academy of Sciences,* 114(7), 1518–1523. https://doi.org/10.1073/pnas.1609244114

## 6.4   Marginal abatement curve

Marginal abatement cost (MAC) curves are a visual illustration of the results of model-based scenarios that convey both the economic impacts of an action or policy and the potential GHG reduction that can be achieved with the action or policy.

Marginal abatement curves are calculated by dividing the net present value (NPV) of an action or policy by the GHG emissions reductions that are generated over the lifetime of that project. NPV estimates the overall current value of a series of cash flows including all future cash flows. It requires an assessment of the dollar value of the initial costs, as well as the costs and benefits over the duration of the project life, discounted in terms of a present value.
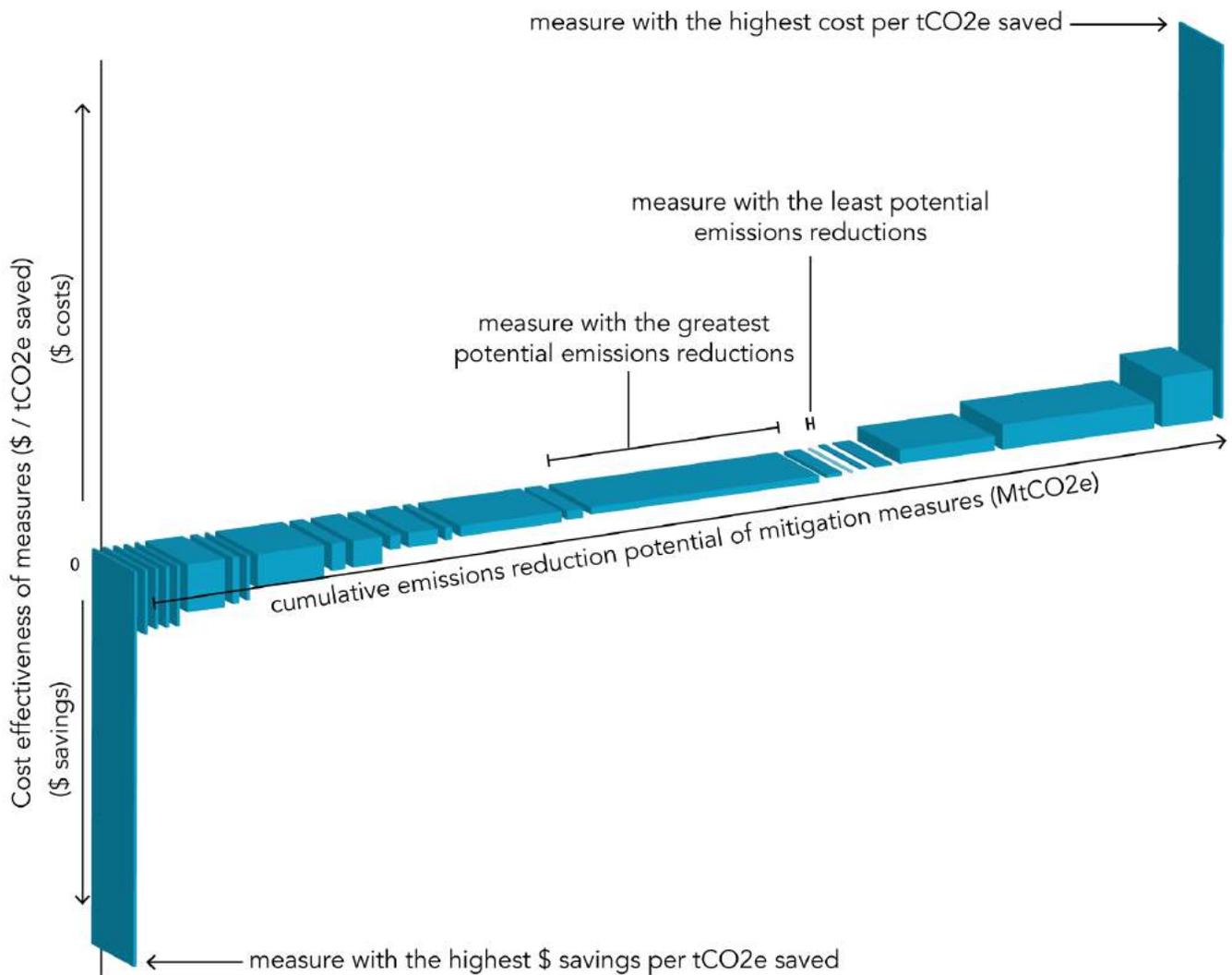
MARGINAL ABATEMENT CURVE FEATURES



*Figure 52. Marginal Abatement Curve components*

MAC curves have three important limitations to note. First, the MAC curve implies that a given amount of GHG reductions is associated with a certain carbon price; in all likelihood there are a number of government and market failures that will inhibit that action even if that level of carbon price is implemented. Second, MAC curves do not provide information on the time dimension of the measures, for example how long it takes to implement a measure. MAC curves do not indicate which actions are more urgent and if there is there is an order to implementation in that one action or policy is required in order to incur reductions from another.[121] Third, MAC curves do not account for distributional impacts, for example who bears the costs and who derives the benefits of policies and actions.[122]

The marginal abatement cost curve is calculated by dividing the net present value of the action by the total GHG emissions saved between 2017 and 2050. The net present value is calculated by adding the capital, operating (which include fuel costs and the carbon price) and maintenance costs or savings for each action.[123] These costs or savings are calculated by implementing the action against the BAP scenario.

The capital investments associated with the low carbon action are tracked each year and the operations and maintenance costs savings associated with that action are tracked for the lifetime of each component. Many actions incorporate multiple components (boilers, air conditioners, insulation) that have different lifetimes.

Financial assumptions were derived from data local to Toronto wherever possible, if not from Ontario, Canada, US and international in that order of hierarchy. Financial sectors were defined including residential buildings, residential equipment and personal use vehicles and the costs or savings for the different sectors are also tracked.  All financial outcomes are converted back to 2016$ using a discounting rate of 3%. The Government of Canada recommends 3% in circumstances where environmental and human health impacts are involved.[124]

The total emissions saved are calculated by applying the action against the BAP scenario. The MAC curve does not reflect the integrated effects either on costs or GHG emissions.

121   Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. M. (2015). *Decarbonizing development: three steps to a zero-carbon future.* Washington, DC: World Bank Group.

122   Saujot, M., & Lefèvre, B. (2016). The next generation of urban MACCs. Reassessing the cost-effectiveness of urban mitigation options by integrating a systemic approach and social costs. Energy Policy, 92, 124–138. https://doi.org/10.1016/j.enpol.2016.01.029

123   The Marginal Abatement Cost does not include the Social Cost of Carbon.

124   Environment and Climate Change Canada. (2016). T*echnical update to Environment and Climate Change Canada's social cost of greenhouse gas estimates.* Retrieved from http://ec.gc.ca/cc/BE705779-0495-4C53-BC29-6A055C7542B7/Technical%20Update%20to%20Environment%20and%20Climate%20Change%20Canadas%20Social%20Cost%2

Financial analysis was not completed for increased solid waste diversion rates and energy storage because of complexities associated with these specific actions.

MARGINAL ABATEMENT CURVE FOR THE CITY OF TORONTO LOW CARBON SCENARIO
($/tCO2e COST PER TONNE SAVED | TOTAL kt CO2e SAVED)



34. Electrify City vehicle fleet ($-6,109 | 321)
24. Car free areas ($-939 | 1,075)
27. Increased walking mode share ($-934 | 231)
12. Re-commissioning commercial buildings ($-701 | 1,600)
33. Zero emissions vehicles for freight ($-525 | 14,890)
28. Electrify transit fleet ($-400 | 5,808)
6. Residential retrofit pre-1984 (Tower Renewal+) ($-212 | 4,494)
17. & 20. District energy ($-163 | 22,390)

30. Increase adoption of EV ($-98 | 50,668)
9. Dwelling retrofit post 1980 (HELP+) ($-14 | 568)
31. Industrial process efficiency ($27 | 3,893)
22. Integrated transit improvements ($5,788 | 1,502)
5. TGS for new buildings (res & non-res) ($384 | 33,718)

11. TGS for renovations ($781 | 11,415)
18. Electric heat pumps ($243 | 21,132)
21. Condensed work week ($0 | 1,419)
36. Generate biogas from wastewater ($-53 | 3,538)
8. Dwelling retrofit pre-1980 (HELP+) ($-126 | 3,618)
7. Residential retrofit post 1984 (Tower Renewa+l) ($-181 | 1,610)
26. Increased cycling mode share ($-222 | 2,430)
32. Last mile solutions in freight ($-401 | 2,976)
15. Offshore wind ($-683 | 163)
10. Retrofit ICI ($-742 | 8,356)
25. Personal transportation planning ($-934 | 358)
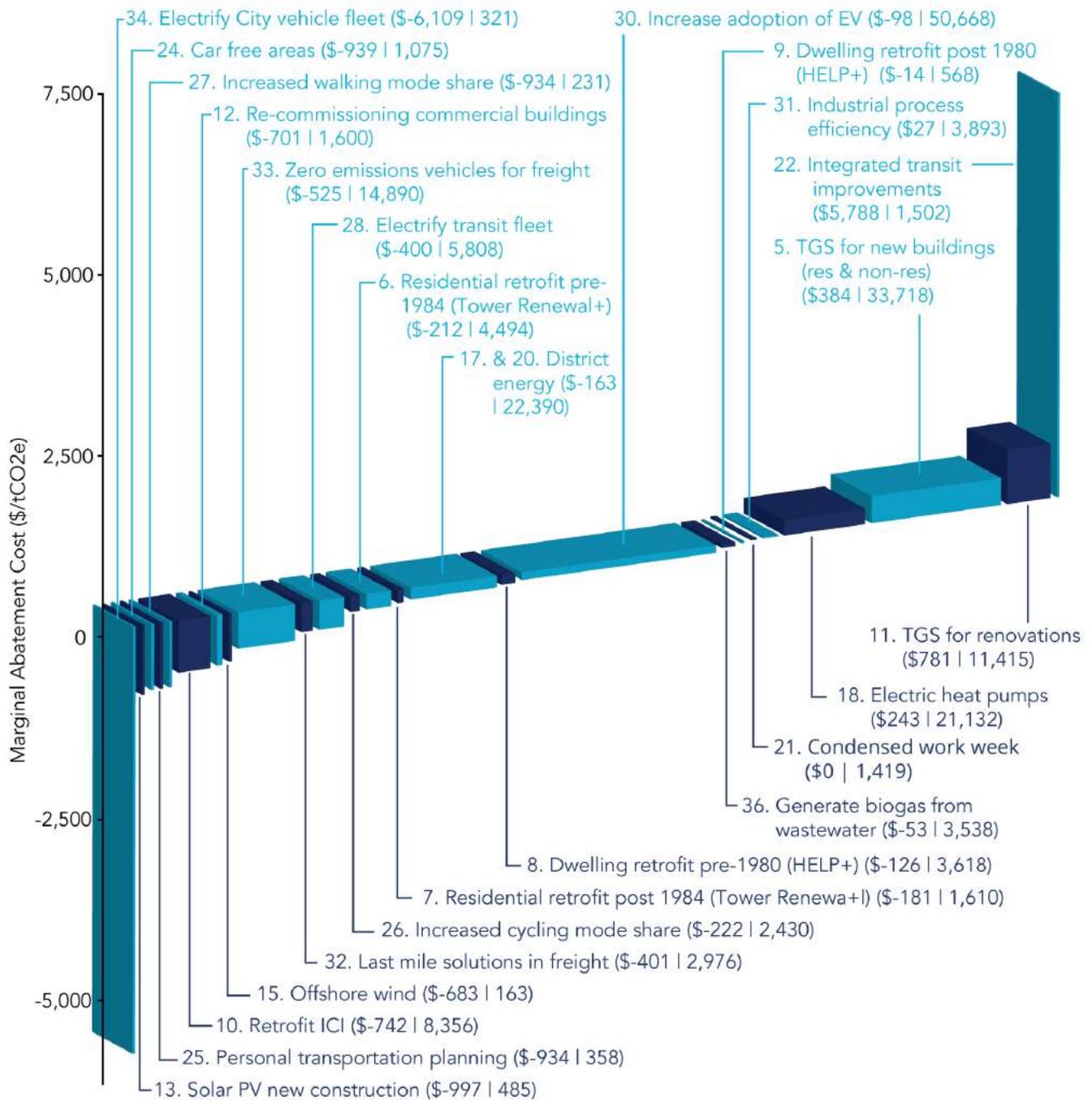13. Solar PV new construction ($-997 | 485)

*Figure 53. Marginal Abatement Curve*

All of the actions which fall below the line represent financial savings, beginning on the left side of the chart and those which are positive or above the line represent costs. Many of the opportunities for emissions reductions, totaling 67% of the GHG emissions reductions, will save money per tonne over the lifecycle of the action (i.e. below the line) and that a few actions, totaling 33%, will cost money, given current technologies and the financial assumptions used to generate the marginal abatement costs.

Making decisions solely according to the abatement cost can limit future emissions reductions because of slow capital turnover, slow technological diffusion, availability of skilled workers, financial constraints and institutional constraints and social norms. For this reason, in a report on decarbonisation, the World Bank indicates that short-term targets need to be optimized for long-term objectives and not short-term objectives. For example, the in the case of decarbonizing the European electricity sector, the optimal approach is not, as a purely financial analysis would indicate, to switch from coal to natural gas to electricity, but rather to invest early in renewable generation to avoid stranded investments in gas power plants.[125]

## 6.5  Multi-criteria analysis

The energy and GHG emissions impacts of different actions were quantitatively assessed in CityInSight but a similar approach is not possible for the co-benefit and co-harms, because of the qualitative nature of each of the areas considered.

In cases in which the impacts cannot be quantified for any of a number of reasons, multi-criteria analysis (MCA) is a useful tool. MCA can incorporate quantitative, monetary and qualitative data in a single framework, as well as varying degrees of certainty for each data set. MCA is also a transparent framework, which clearly illustrates the rationale behind the rating system.

MCA consists of four steps. First, criteria are identified and as a second step, those critera are weighted in accordance with their relative importance. Third, options are identified and fourth, the actions are scored against the criteria. The result is a prioritized set of options, ranked according to their performance against the criteria.

In the case of TransformTO, MCA was used to identify the co-benefits of bundles of relevant actions against criteria which were first identified in a literature review and then were subsequently revised and weighted by the Modelling Advisory Group (MAG). Figure 54 shows the final weighting of the criteria, with public health, clean air and quality affordable housing achieving the highest weighting of the criteria.

125  Lecuyer, O., & Vogt-Schilb, A. (2014). Optimal transition from coal to gas and renewable power under capacity constraints and adjustment costs. World Bank Policy Research Working Paper, (6985). Retrieved from http://papers.ssrn.

The MAG was assembled to provide advice to the City of the Toronto Environment and Energy Division and The Atmospheric Fund. The MAG included 35 volunteer members representing multiple sectors within the community and multiple City of Toronto divisions and agencies. The MAG's primary role was to support the scenario modeling process, to undertake the MCA of proposed low-carbon solutions and to offer advice to staff on how to create the TransformTO pathway. For information on the MAG members, please refer to the Acknowledgments section.

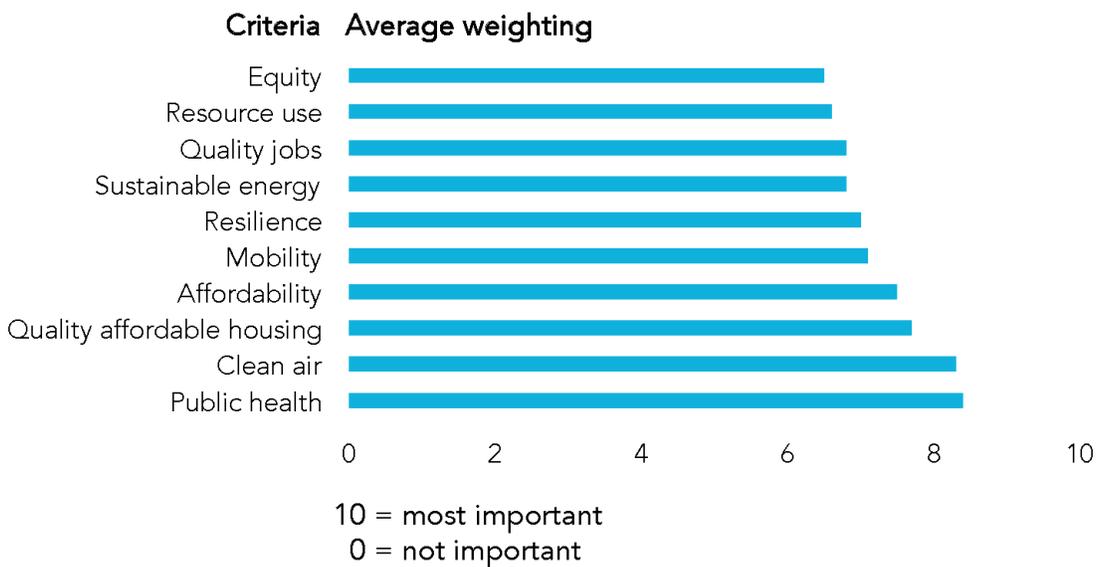CRITERIA WEIGHTS FOR EMISSIONS REDUCTION ACTIONS CO-BENEFITS ANALYSIS



10 = most important
0 = not important

*Figure 54. Criteria by weight*

Each bundle of actions was scored against each of the criteria, in order to generate a weighted score. Based on the collective judgment of the MAG, those actions with the highest score, make the greatest contribution to co-benefits in the city; these are the optimal actions in terms of co-benefits.

The variation in scores for each criteria is evident from the size of the relevant coloured bar in Figure 55. For example, the MAG scored active transportation as the best performing action against the criteria of public health, followed by transit.

*Figure 55. Results of the multi-criteria analysis*

The findings of the MCA provide important guidance to the City in:

- Prioritizing implementation efforts: In a constrained environment, resources will be allocated to those actions which deliver the most benefits. The MCA is a transparent evaluation of the benefits that actions will generate beyond their contribution to GHG emissions reductions.

- Identifying responsibility and/or mechanisms for implementation: Some actions provide a wide range of benefits and are therefore more appropriate for public investments. The involvement of

the private sector may be appropriate for actions which provide fewer co-benefits, which implies that implementation will be more straightforward.

- Identifying actions which are likely to be most supported: Various organizations and constituencies will have an interest in actions which deliver benefits other than GHG emissions. Last mile solutions for freight, for example, will garner less support than decentralized renewable energy, as there is a broader set of reasons to support decentralized renewable energy.

- Seeking to maximize GHG emissions reductions from those actions with the greatest co-benefits: Is it possible to innovate with transit in order to achieve more GHG emissions and reduce the requirement for electrification of private vehicles, which results in fewer co-benefits.

RELATIONSHIP BETWEEN CO-BENEFIT SCORES AND GHG REDUCTION POTENTIAL OF PROPOSED ACTIONS
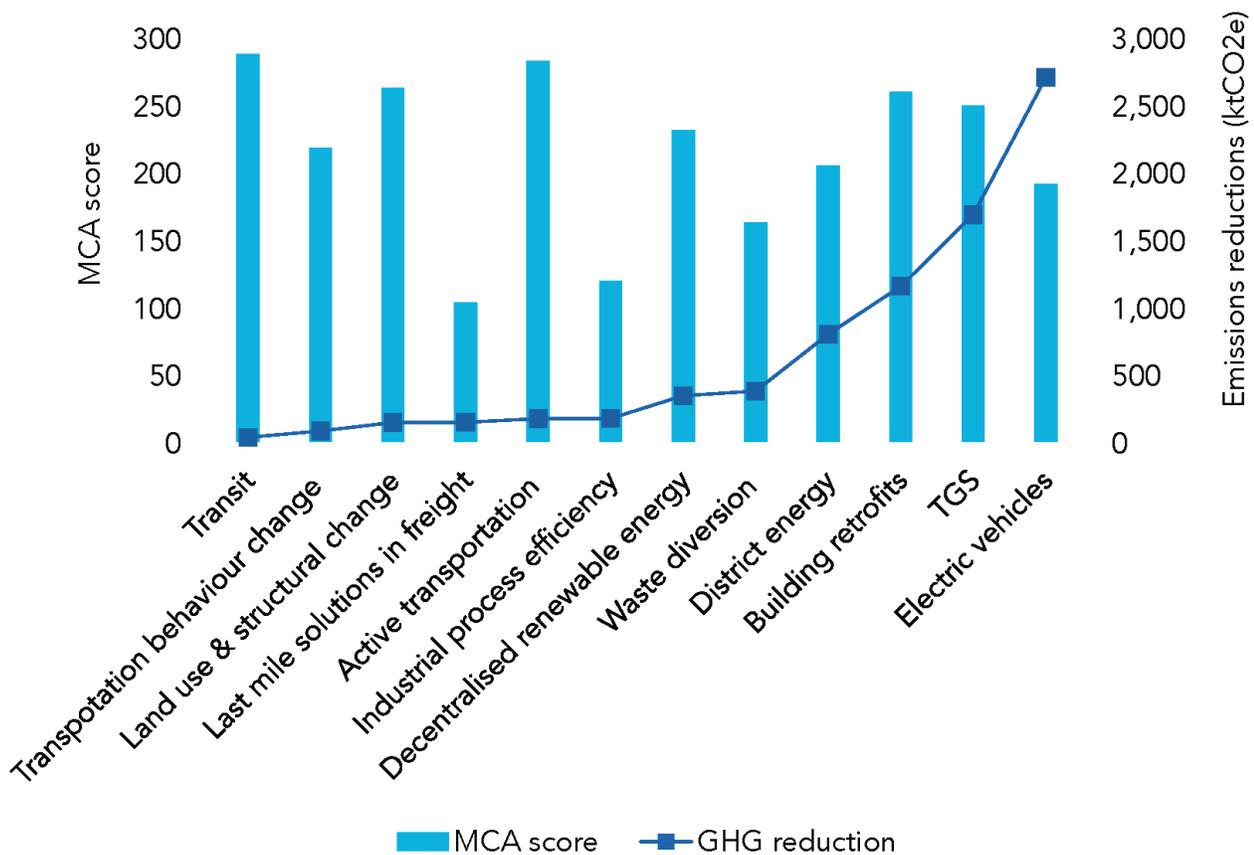


*Figure 56. MCA score and GHG emissions reductions*

One notable finding was that a higher level of GHG emissions reductions does not correlate with a greater perception of co-benefits; in fact, many of the actions that result in higher levels of GHG emissions scored lower in the MCA, as illustrated in Figure 56.  For example, electrification of vehicles is fourth from the bottom on the MCA score, but delivers the most GHG emissions reductions. While electric vehicles deliver benefits in terms of clean air, the impact on other criteria is perceived to be less significant or negligible. On the other hand, enhanced transit provides extensive co-benefits, but the GHG emissions reduction is much lower.

The MAG's full set of recommendations and related process documents can be found on TransformTO's website.

# 7. Managing uncertainty

Uncertainty is a significant factor in this analysis, from developing the baseline and reference case to assessing the impacts on GHG emissions and co-benefit and co-harms. The World Bank has characterized this condition as deep uncertainty and recommends the following guidelines for policy development:[126]

1. Avoid making irreversible decisions and becoming locked into patterns or technologies that would be difficult and costly to reverse if new information or changing preferences arise.

2. Climate policies should be robust, in that they should perform well under a broad range of possible futures, rather than just being optimal for the most likely future.

3. Climate policies need to combine multiple policy goals and create consensus.

The guiding metrics recommended are synergies, when a policy or action provides net local and immediate co-benefits, and urgency, when a policy or action is associated with economic inertia. Table 10 illustrates how different actions can be categorized in terms of synergy and urgency. The prioritized actions are those with greater inertia and risk of irreversibility as well as more positive synergies. In this case, actions which satisfy those two considerations are land-use planning and public transit. The provision of renewable energy is easier to implement at any point and does not provide as many synergies and therefore is a lower priority.

126  Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. M. (2015). Decarbonizing development: three steps to a zero-carbon future. Washington, DC: World Bank Group.

*Table 10. Example of analysis of measures using synergies and urgency.*[127]

| | | SYNERGIES | |
|---|---|---|---|
| | | Low or negative (trade-offs) (to be considered at higher level of income or paid for by external funds) | Positive (attractive regardless of income, provided that financial mechanism can be found) |
| URGENCY | Low: less inertia and irreversibility risk | • Installation of heat pumps<br><br>• Installation of solar PV systems | • Retrofits in buildings |
| | High: greater inertia and irreversibility risk | • Electrification of vehicles<br><br>• District energy systems<br><br>• Building code improvements | • Land-use planning<br><br>• Public urban transport and transit-oriented development |

# Sensitivity analysis

The LCS illustrates the GHG emissions reductions of a potential pathway for the City of Toronto to achieve its 80x50 target; and is built on the assumptions as described above in this report and in technical reports. In that light, it reflects what is anticipated to occur in the future if the actions as described are implemented. Sensitivity analysis can provide insight on what might happen if assumptions vary from the path described, identifying significant assumptions.

Sensitivity analysis involves the process of adjusting certain selected variables within the model in order to identify variables that have the most significant impact on the LCS. It is not a process of "scenario analysis", as the variables tested do not represent internally consistent scenarios. The approach used adjusted those variables that were identified as having a higher potential to "move the curve", in order to be better informed about the implications of future options.

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127  Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. M. (2015). *Decarbonizing development: three steps to a zero-carbon future.* Washington, DC: World Bank Group.

The process applied a judgment-based "one-at-a-time"[128] exploration of variables within the LC scenario. The results should not be viewed as an evaluation of fully considered alternative futures, rather, it is an exploration revealing how a selected output (i.e. emissions) responds to changes in selected inputs (e.g. # residential units).

Several variables were identified for sensitivity analysis; the assumptions and results of each are described in Table 11. The impact (expressed in Mt CO2e) shows the absolute emissions difference relative to the LCS in 2050.

*Table 11. Sensitivity analysis variables and results.*

| CATEGORY | VARIABLE ADJUSTMENT | IMPACT (MT CO2E); % +/- RELATIVE TO LC IN 2050 |
|---|---|---|
| **BUILT FORM** | | |
| Decrease population & employment-population grows more slowly. | -10% dwelling units with reduced population -10% non-residential floorspace with reduced employment | -0.24 MT; (-6.1%) |
| Increase population & employment-population grows more quickly. | +10% dwelling units with increased population +10% non-residential  floorspace with increased employment | +0.24 MT; (+6.1%) |
| **HEATING DEGREE DAYS (HDD)** | | |
| Hold HDD fixed-anticipated climatic impacts are less than anticipated. | Keep number of heating degree days fixed at baseline value. | +0.58 MT; (+14.8%) |
| Decrease HDD-anticipated climatic impacts are greater than anticipated. | Decrease number of heating degree days for 2040 and later by 10%. Linearly interpolate for 2012-2039. | -0.12 MT; (-3.1%) |

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128   One-factor-at-a-time involves changing only one variable at a time to see what effect it produces on the output; generally involves changing one input variable while keeping others at their baseline (nominal) values, then returning the variable to its nominal value, and repeating for each of the other inputs in the same way.

| CATEGORY | VARIABLE ADJUSTMENT | IMPACT (MT CO2E); % +/- RELATIVE TO LC IN 2050 |
|---|---|---|
| **GRID ELECTRICITY EMISSIONS FACTOR (EF)** | | |
| Decrease EF- the provincial electricity grid becomes cleaner. | Natural gas is considered a transition fuel towards a clean grid. Post 2020 all NG turbines are decommissioned at end of life (20 years) and replaced by carbon free sources; 1.59 g CO2eq/kWh in 2050 (BAP 37.4 g CO2eq/kWh in 2050) | -0.94 MT; (-24.0%) |
| Increase EF- more fossil fuel generation is added to the provincial electricity grid | NEB data derived capacity factors that use less nuclear and hydro and more natural gas; 76 g CO2eq/kWh in 2050 (BAP 37.4 g CO2eq/kWh in 2050) | +1.00 MT; (+25.6%) |
| **RETROFITS** | | |
| Decrease residential retrofits- the rate of retrofitting is slower. | Decrease residential retrofits by 25% in LC scenario (# units retrofitted to 2050 in action 6-9). | +0.21 MT; (+5.4%) |
| **ELECTRIC VEHICLE (EV) ADOPTION** | | |
| Decrease in EV uptake in all vehicle stocks- the rate of purchase of EV is slower. | Reduce 2050 EV share of light-duty vehicle stocks by 62%, compared to the Low Carbon scenario (100%) and BAP (22%).<br><br>For 2050 non-stock vehicle activity reduce EV share to 45% compared to LC (90%) and BAP (~0%). | +1.53 MT; (+39.1%) |
| **VEHICLE KILOMETRES TRAVELLED (VKT)** | | |
| Increase VKT- people drive further- increased number of trips or increased trip length. | Gradual increase in passenger vehicle VKT by 20% in 2050. | +0.03 MT; (+0.8%) |

| CATEGORY | VARIABLE ADJUSTMENT | IMPACT (MT CO2E); % +/- RELATIVE TO LC IN 2050 |
| --- | --- | --- |
| Decrease VKT- people drive less- decreased number of vehicle trips or trip length decreases. | Gradual decrease in passenger vehicle VKT by 20% in 2050. | -0.02 MT; (-0.5%) |
| **DISTRICT ENERGY (DE) FUEL MIX** | | |
| Decrease renewable share in DE systems- increased use of natural gas. | Decrease renewable fuel share in additional DE from 100% (assumed in LC) to 50%; assume the other 50% is supplied by conventional natural gas. | +0.68 MT; (+17.4%) |
| **METHANE** | | |
| Global warming potential (GWP) of methane- methane is a more potent GHG emission over 20 years than over 100 years. | Adjust methane GWP from 100-yr (used in LC) to 20-yr GWP | +0.63 MT; (+16.1%) |

CHANGE IN YEARLY PROJECTED EMISSIONS FROM LOW CARBON SCENARIO ACTIONS, 2011 - 2050
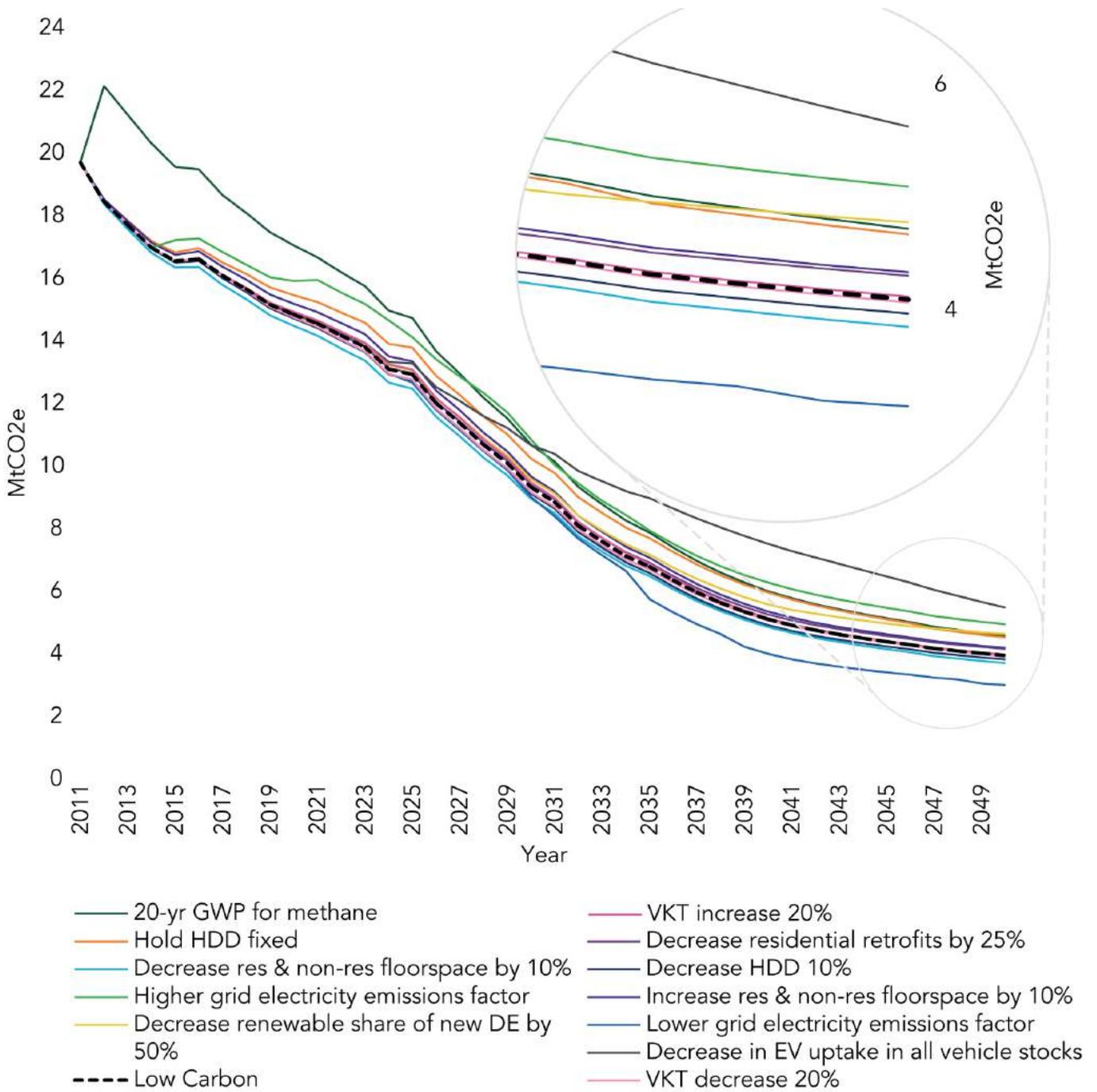
*Figure 57. Change in LC projection for modelled variables.*

**SENSITIVITY ANALYSIS OF THE CITY OF TORONTO BUSINESS AS PLANNED AND LOW CARBON SCENARIOS, 2011 - 2050**

**Estimated emissions**
- – BAP
- ···· Low Carbon

**Sensitivity results**
- BAP
- Low Carbon
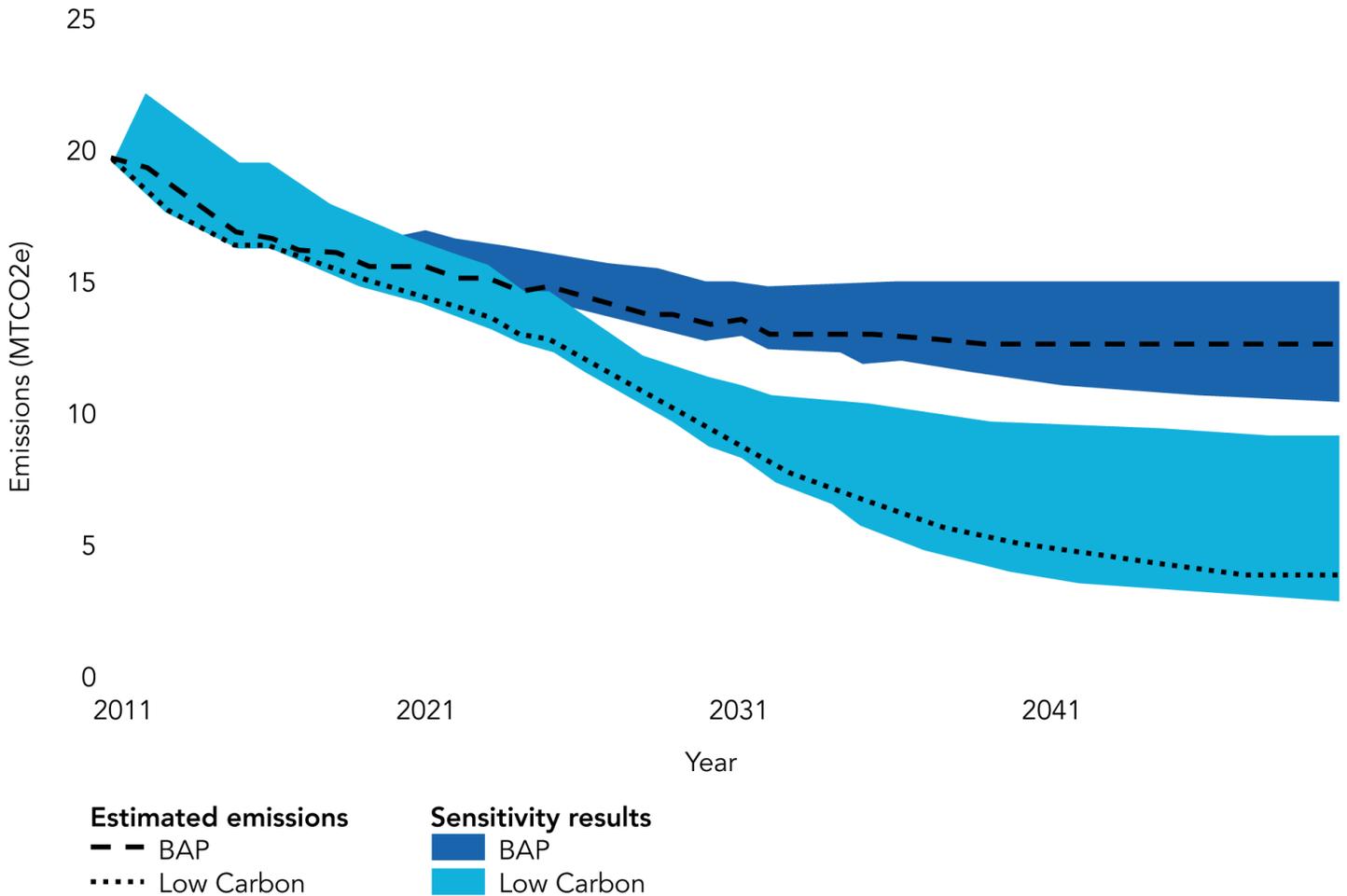
*Figure 58. Sensitivity analysis.*

Changes in assumptions for HDD, grid electricity emissions factor, uptake of electric vehicles, district energy fuel mix, and the GWP of methane have the most significant impact on the GHG emissions trajectory. Those variables with the least impact include changes in VKT and residential retrofit rates.

Heating degree days appear to be muting the impact of increasing population growth on emissions; if it is assumed that HDD are constant over the time period (i.e. the climate does not change, and winters do not become warmer), the results indicate an increase in emissions (+14.8%), and the impact of the population growth becomes more apparent.

Changes in the grid electricity emissions factor appear to have significant influence; as there is a major shift towards electricity in the low carbon scenario, it is fundamental that the emissions factor of new capacity remain low or the electrification approach is at risk from a GHG emissions perspective.

Electric vehicle (EV) uptake in the low carbon scenario plays a major role in the decrease of emissions in the transport sector. Reducing the share of EVs in the vehicle stock to 62% in 2050, compared with 100% in LCS, results in an increase in emissions of 1.53 Mt CO2e, which is 39.1% higher than the projected 2050 emissions of the LCS.

Global warming potential (GWP) is a measure of how much energy the emissions of 1 tonne of a gas will absorb over a given period of time, relative to the emissions of 1 tonne of carbon CO2. That time period is generally 100 years. However, certain gases have a much bigger impact over a 20-year period, which is the period of concern in terms of preventing dangerous levels of climate change. Methane for example, has a much shorter lifetime than CO2 and absorbs more energy over a 20-year period than 100-yr; subsequently, its 20-year GWP is much higher at 86, compared with its 100-yr GWP of 34.

Using the 20-yr GWP for methane of 86, compared with 34 in the LCS, results in an increase of 0.63 Mt CO2e in 2050. The immediate spike in emissions in 2012 in Figure 58 is as a result of changing the GWP factor of methane.

In terms of risk to the City of Toronto's 2050 target, increased fossil fuel generation in the Provincial electricity grid is a major risk as this would jeopardize the emissions reduction value of fuel switching efforts in the building and transportation sectors. This risk is difficult to mitigate, unless the City embarks on massive city-owned renewable energy projects to displace the impact of increased emissions from the grid. If the emissions factor of the grid is maintained or decreased, the next most significant risk is if the uptake in electric vehicles is slower than modelled. In this case, the City can focus its efforts on reducing emissions by reducing VKT. However, the modelling has indicated that significant reductions in VKT are difficult to achieve.

Relying on renewable natural gas in the district energy system is also a risk. If the availability of renewable sources, including the anticipated supply of renewable natural gas, are less than anticipated, significant emissions could result from the district energy system.

# 8. Discussion items

## 8.1 Regional emissions

The City of Toronto's GHG emissions are significantly influenced by the activities of people in the surrounding municipalities. Conversely, the GHG emissions of the surrounding municipalities are significantly influenced by the activities of people living within the City's boundaries. The analysis of inbound and outbound external trips highlighted this interdependency; no matter how much the transit lever was pushed in the City of Toronto, the vehicular mode share of the trips beginning or ending outside of the City barely moved.

If the City of Toronto establishes an advanced green building standard that comes with an increased price, there is a risk that this may spur additional- and less efficient housing beyond the boundaries of the City of Toronto. For these and other reasons, collaborating with other municipalities in the City of Toronto's "commutershed" to harmonise approaches and transfer expertise would enhance the ability of the City of Toronto to achieve its emissions targets.

## 8.2 Carbon budget

The pathway to the 2050 target facilitates the identification of a carbon budget for the city, essentially the total emissions under the curve of the low carbon trajectory.  The carbon budget is an important concept in terms of understanding the cumulative impacts of the city's low carbon pathway.

The cumulative emissions reduction of the LCS for the city between 2017 and 2050 is 175 Mt; compared to the total emissions under the BAP of 484 Mt CO2e, this results in a carbon budget of 309 Mt, that is, the cumulative emissions remaining under the LCS. From another perspective, the low carbon budget would be exhausted within 19 years if the level of emissions in 2017 (16.4 Mt CO2e) were continued.

## CITY OF TORONTO'S CARBON BUDGET 2016 - 2050 (MTCO2e)



484

309

Low carbon

BAP
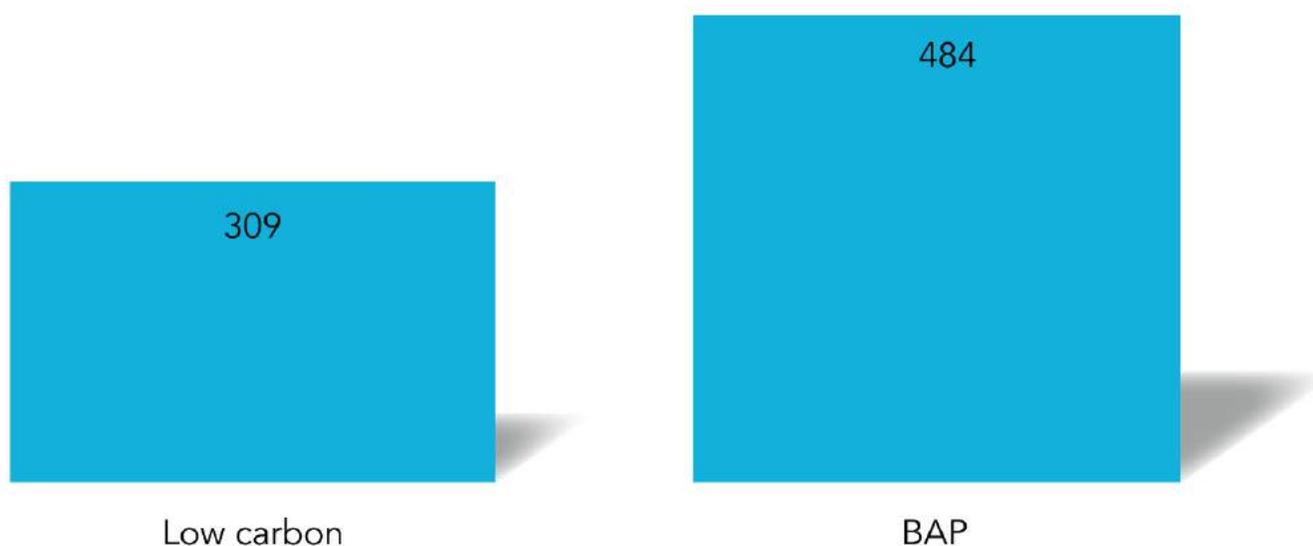
*Figure 59. Toronto's carbon budget.*

The cumulative carbon budget helps to make the targets real. For example, the City has a total of 309 Mt CO2e of emissions between 2016 and 2050. Each year, the remaining emissions available in the budget decline and the implications of those reductions for the remaining years in the time period are immediately apparent. If more rapid emissions reductions are achieved than anticipated, than the City is on track; if not, then it is immediately apparent that more significant action is required.

## 8.3   Carbon sinks

Carbon sinks were not included in the GHG analysis within this report, because the potential for emissions reductions was deemed to be low in the context of the City of Toronto. An analysis of the City of Toronto's trees estimated that they sequester 36.5 ktCO2e each year,[129] however, this is a background rate of sequestration and maintaining this rate already requires major tree planting efforts. For this reason, forests were not incorporated as a potential source of additional reductions in the LCS.

In addition to forests, there are other opportunities to reduce emissions using carbon storage, including in green roofs which can be integrated with solar

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129   City of Toronto. (2013). Every tree counts: A portrait of Toronto's urban forest. Retrieved from http://www1.toronto.ca/City%20 Of%20Toronto/Parks%20Forestry%20&%20Recreation/Urban%20Forestry/Files/pdf/E/every_tree_counts.pdf

panel installations. A green roof can sequester 0.4 kg CO2e per m2.[130]  An innovative process by the company CarbonCure embeds 18 kg of CO2 into each cubic metre of concrete, causing the concrete to cure more quickly.[131] This process is already being used by the major concrete masonry suppliers in Toronto. Future investigation into novel approaches to carbon storage is recommended as a seperate analysis in order to better understand the potential scope for Toronto.

## 8.4   Consumption-based inventories

In the discussions related to the City of Toronto's GHG emissions targets, the idea of a consumption-based GHG inventory was raised, an alternative to tracking emissions by sector using a geographic approach. The analysis completed in this report is guided by the Global Protocol for Community Scale Greenhouse Gas Emissions Inventories, using a geographic approach. This approach accounts for emissions that result from the various sectors within the geographic limits of the city and some GHG emissions, resulting from electricity production outside of the city's boundaries, are also tracked. A consumption-based approach seeks to track all GHG emissions associated with the goods and services consumed by individuals living in the City of Toronto, while excluding goods and services which are exported. This approach typically uses an input-output model, which links consumption patterns and trade flows to energy use and GHG emissions. Consumption-based inventories typically result in higher emissions on a per capita basis than sector-based inventories in 'consumer cities' like Toronto,[132] and the opposite is true for cities in the Global South which are producing goods for consumers in the North. The results, which focus on patterns of consumption, can provide additional insights into sources of emission and create opportunities for new municipal policies.

## 8.5   Vehicle efficiency standards: At risk of a rollback

One of the variables that contributed to the downward trend in GHG emissions in the BAP was the fleet wide fuel efficiency standards which the Government of Canada has harmonized with the US Government. The US Government has indicated that it will roll back vehicle efficiency standards, which has the potential to impact this assumption in the modelling results, by approximately 4.5 Mt CO2e per year in reductions by 2050. The rollback is not assured and the state of California has indicated that it will move ahead

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130   Getter, K. L., Rowe, D. B., Robertson, G. P., Cregg, B. M., & Andresen, J. A. (2009). Carbon Sequestration Potential of Extensive Green Roofs. Environmental Science & Technology, 43(19), 7564–7570. https://doi.org/10.1021/es901539x

131   Personal communications with CarbonCure, January, 2017

132   Seto, K. C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G. C., Dewar, D., … others. (2014). Human settlements, infrastructure and spatial planning. Retrieved from http://pure.iiasa.ac.at/11114/

with the regulations irrespective of the US Government.[133] Canada has given no indication that it will adjust its direction.[134]  Making the case for more aggressive electrification, beyond the current standards is a key aspect of the LCS.

## 8.6   Discounting

The rate of discounting has a significant impact on the financial performance of the actions in the LCS, particularly since many of the investments require early capital and result in avoided costs at the end of the period considered.

Discounting is based on the idea that future consumption is worth less than present consumption, firstly because if consumption continues to grow into the future, one unit of consumption will be valued less than that same unit of consumption is valued today. Secondly, people prefer consumption today rather than tomorrow.

The issue of climate change challenges both of these assumptions.[135] In the first case, the impacts of climate change pose an existential threat to the prospects of continuing growth into the future. In the second case, discounting future consumption discriminates against future generations, on the basis of birth.

For this reason, a discounting rate recommended by the Government of Canada of 3% was used for this analysis.[136]

## 8.7   Long-term planning

Directly related to the considerations around discounting and the carbon budget is the importance of long-term planning. City planners and transportation planners are more accustomed to looking thirty or more years into the future than most other professions. The impacts of city infrastructure on GHG emissions require a new emphasis on long-term planning, and therefore on managing uncertainty. The infrastructure that is built now determines trajectories of GHG emissions for thirty years or more. If this infrastructure is retired or replaced prior to the end of its lifetime, costs

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133   Mulkern, A, A. (2017). California forges ahead with clean cars rules. Retrieved March 28, 2017, from https://www. scientificamerican.com/article/california-forges-ahead-with-clean-cars-rules/

134   Mccarthy, S., & Keenan, G. (2017, March 15). Trump targets fuel-efficiency standards. *The Globe and Mail.* Retrieved from http://www.theglobeandmail.com/report-on-business/in-victory-for-auto-makers-trump-orders-review-of-vehicle-emissions-rules/article34312126/

135   Stern, N. (2006). The Stern review on the economic effects of climate change. Cambridge University Press. Retrieved from https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull48-2/48205692528.pdf

136   Boardman, A. E., Moore, M. A., & Vining, A. R. (2008). Social discount rates for canada. In John Deutsch Institute Conference: Discount Rates for the Evaluation of Public-Private Partnerships. Kingston, ON. Accessed September (Vol. 22, p. 2011). Retrieved from http://jdi-legacy.econ.queensu.ca/Files/Conferences/PPPpapers/Moore%20conference%20paper.pdf

include the opportunity cost associated with some of the most expensive infrastructure that society builds, the cost of removing or reconfiguring the infrastructure including buildings, roads, water and wastewater pipes and the cost of introducing new low or zero carbon infrastructure. Careful consideration using techniques such as scenario planning and appropriate incentives and regulations that reduce the risk of stranded municipal and private investments will either minimize the upfront cost of the low carbon pathway, while generating new economic opportunities.

## 8.8 The cost of doing nothing

This report focuses on the benefits of implementing a Low Carbon pathway. Conversely the risk of doing nothing is also significant. Risk is defined as the probability of an event combined with the severity of its impacts. In the context of this analysis, risks include a slower response to mitigation and therefore more severe impacts of climate change, a missed opportunity to transition to low carbon urban systems and therefore an increased burden on the City, households and the private sector to support the transition. It is also a missed opportunity for leadership in the public and private sectors and a missed opportunity to acquire the co-benefits in improved health outcomes, economic development, a more resilient energy system and improved quality of living that are synergistic with the LCS.

# 9.   Conclusions

## 1.   The low carbon pathway is technically feasible using current technology.

The modelling demonstrates that by applying existing technologies, the City of Toronto can achieve its GHG target of 80% reductions by 2050 over 1990 levels. The LCS is but one pathway and other pathways that achieve the City of Toronto's target are also possible.

## 2.   The City has a solid foundation

The direction of a number of the City's existing policies, including in land-use and solid waste is congruent with the 80% target. The City also has many of the existing programs in place required to implement the LCS, including in building codes, retrofits, district energy, renewable energy and transit.  These programs need to be massively scaled up to achieve the 80% target.

## 3.   The City of Toronto is an urban energy system and all of the pieces need to be considered as an integrated whole.

Considering actions in the context of an urban energy system is critical in order to avoid higher capital costs than necessary or over-inflated expectations for GHG emissions reductions. The results of the integrated GHG emissions scenario are very different than the results of a wedge by wedge implementation. The order in which actions are implemented also matters, influencing both the effectiveness and cost of the action and subsequent actions.

## 4.   Land-use, district energy and transit investments can result in positive feedback cycles.

Using land-use policies to direct future development into particular areas can not only increase the access of the future development to transit and district energy, but that future development can also tip the balance of a neighbourhood from no district energy to district energy and to higher levels of transit service, resulting in

disproportionate GHG emissions reductions. Investments in transit and district energy can attract density, which may support additional investments in transit, resulting in a positive feedback cycle.

## 5. There are key actions, but the actions work together.

While all of the actions are required to support the LCS, there are certain actions that are non-negotiable in order to achieve the 80% target. Fuel switching via electrification of the personal and commercial vehicle fleet is necessary to reduce gasoline and diesel consumption. The installation of heat pumps and district energy facilitates the transition to renewable heating. Energy retrofits in buildings result in reduced energy consumption but also reduce the capital costs of the transition, by generating a flow of avoided costs. Many of the actions are inter-related and if one action scales back its efforts on GHG emissions, other actions have to scale up their ambition, and given current technologies, there is likely a high cost associated and there may also be physical limits on the potential reductions

## 6. The low carbon pathway provides societal benefits and achieves multiple objectives.

The Low Carbon pathway as a whole improves health outcomes, provides new economic opportunities, improves quality of life, and depending on the implementation mechanisms, may enhance equity. The most significant co-benefits include reduced air pollution, increased health benefits associated with walking and cycling, avoided damages associated with climate change impacts (represented by the Social Cost of Carbon) and the economic stimuli associated with the LCS, including jobs and new business opportunities.

The alternative, the cost of doing nothing, was not evaluated in full from the perspective of co-harms or co-benefits, but this alternative represents risks in enhanced damage from climate change, avoided economic opportunities, and reduced societal benefits. Notably, the Low Carbon pathway unlocks investments which are not otherwise available, for example, retrofitting most of a building stock within a city and establishing a major district energy system, both of which would be major economic stimuli.

## 7. The low carbon pathway requires major capital investments, most of which will generate financial returns.

The Low Carbon pathway requires major new investments, totaling $60 billion between the period of 2017 and 2050, using a discounting rate of 3%. The marginal abatement curve showed that 67% of the emissions reductions will save money over their lifetime and that a few actions, totaling 33% of the GHG emissions reductions, will cost money, given current technologies and the financial assumptions used to generate the marginal abatement costs. Actions save money by avoiding capital and maintenance expenditures, energy costs and the cost of carbon.

It is of particular importance to analyze the financial implications in a model that reflects the integrated energy system. Without the full picture, investments could be stranded. For example, district energy systems may be scaled based on buildings prior to energy efficiency retrofits, reducing or eliminating the financial benefit of the action.

Many of the investments are front-loaded and the benefits incur towards the end of the time period. The overall financial benefit is therefore highly sensitive to the rate of discounting. If a higher discounting rate is used, the financial case for some of the actions may be reduced or eliminated. The savings at the end of the period are in part due to the learning effect, as society learns how to undertake building retrofits on a large scale, but the advantages of the learning rate require immediate action.

## 8. The price of carbon is a key factor in the economic case for many of the actions

In the context of an 80% reduction in GHG emissions, the price of carbon becomes an important variable in contributing to the financial case for particular actions. By 2050, the LCS results in just over $1 billion per year in avoided costs for the price of carbon. It is therefore in the City's interest to advocate for an increasing price of carbon to support the achievement of City Council's 80% GHG reduction target.

## 9. The prioritization of actions can be determined by three primary factors: the window of opportunity to replace infrastructure at the end of its lifetime, the co-benefits incurring and the cost effectiveness of the measure in reducing emissions.

Hot water heaters will turnover three times between now and 2050, providing three opportunities to upgrade the efficiency or switch to different fuel types. Residential buildings built today, however, will still be around in 2050; decisions on shape, size and energy performance for buildings today therefore have direct implications on the 2050 target. This is not to say that interventions cannot be made midway through the lifetime of an investment, but the societal cost, in terms of finances, materials and energy will be higher. The opportunities for making the lower-cost shift to a low or zero carbon building or technology diminish year over year, so immediate action is crucial to maximizing the financial benefit. If the opportunity is missed, an additional effort and cost is required to undo what was done.

Co-benefits and co-harms are difficult to quantify, because each one involves different considerations. Multi-criteria analysis provides an effective strategy to draw on diverse expertise in order to identify the impact of different actions. The MCA results indicate that there is not a direct correlation between actions which maximizing co-benefits and maximizing GHG reductions. The implication is that in some cases the GHG reduction can be the primary driver for the action, whereas in other cases, a co-benefit may be the primary driver.

## 10. Ongoing measuring and verification is critical to monitoring progress and making course corrections.

The future is full of uncertainty and the assumptions used to develop the BAP and LCS will change year over year as external conditions change, technologies evolve and the city develops. A key example is autonomous vehicles. The LCS makes certain assumptions around the impact of AVs, but the actual impact is unknown. Monitoring and evaluating progress on an ongoing basis will ensure ongoing adaptation to evolving circumstances. The carbon budget is a useful tool to continually monitor progress towards the 2050 target.

NEXT TRAIN
KENNEDY

EXIT

Bell

# Glossary

**80 x 50** refers to reducing emissions by 80% by 2050 based on 1990 levels.

**Autonomous vehicles** are also known as self-driving vehicles; vehicles in which at least some aspects of a safety critical control function (e.g., steering, acceleration, or braking) occur without direct driver input.

**Baseline** is the starting year for the energy or emissions projection.

**Biogas** is a source of renewable energy, specifically methane, that is derived from the process of bacterial decomposition of sewage, manure, waste, plant crops, or other organic waste products.

**Building retrofit** refers to changes to the structure or systems of an existing building. Building retrofits allow for reductions in energy and water consumption with the use of more efficient technologies, products, and designs, and can improve amenities for the building's occupants.

**Bus rapid transit (BRT)** is a bus system that aims to combine the capacity and speed of a metro with the lower cost and flexibility of a bus system. Typically, BRT systems have dedicated right of ways.

**Build-as-planned (BAP)** is a scenario designed to illustrate energy use and greenhouse gas emissions if no additional plans, policies, programs and projects are implemented.

**Capacity factor** is the ratio of a power plant's actual output over a period of time to its potential output if it were possible to operate continuously over the same period of time.

**Carbon budget** is is the maximum amount of carbon that can be released into the atmosphere while keeping a reasonable chance of staying below a given temperature rise.

**Carbon dioxide equivalent (CO2e)** is a measure for describing the global warming potential a given type and amount of greenhouse gas may cause, using the equivalent amount or concentration of carbon dioxide (CO2) as a reference. CO2e is commonly expressed as million metric tons of carbon dioxide equivalent (MtCO2e).

**Cooling degree days (CDD)** aret he number of degrees that a day's average temperature is above 18 degrees celsius requiring air conditioning.

**Combined Heat and Power (CHP)**, also known as cogeneration, CHP is the simultaneous production of two or more useful forms of energy from a single device, typically electricity and useful heat.

**Corollary benefits (co-benefits)** refers to benefits that are additional to the primary objective.

**Discount factor** is the ratio applied to current values in order to derive a value for future annual revenues and costs; it reflects factors such as perceived future risk and the premium that is placed on immediate revenues and deferred costs.

**District energy systems** provide heating and/or cooling to multiple buildings from centralised energy provision systems.

**Distributed generation** refers to technologies that allow consumers to generate electricity on site through solar photovoltaic (PV) systems, combined heat and power (CHP), and/or other technologies.

**Economic prosperity** is defined as the capability to flourish.

**Energy efficiency improvement** is an improvement in the ratio of energy consumed to the output produced or service performed. This improvement results in the delivery of more services for the same energy inputs or the same level of services from less energy input.

**Equity** is the absence of avoidable or remediable differences among groups of people, whether those groups are defined socially, economically, demographically, or geographically.

**Electric vehicles** are an umbrella term to describe a variety of vehicle types that use electricity as their primary fuel source for propulsion or as a means to improve the efficiency of a conventional internal combustion engine.

**Energy storage** refers to technologies that save generated energy and use it at another time. Energy storage includes electric systems such as batteries as well as thermal systems such as hot and cold water storage tanks.

**Fuel poverty** refers to a situation in which a household technically has access to energy but cannot afford adequate energy services to meet their basic needs (see Box 4.1).

**Impact** is any kind of result from an action or measure. In this publication, impact is used to describe any result, positive or negative, arising from an

energy efficiency measure. In this context, the impact could be reduced energy consumption, for example, or increased economic activity (which may drive up energy consumption overall).

*Geothermal* is heat from the earth that can be used as a renewable source of energy.

*Greenhouse gases (GHG)* are gases that trap heat in the atmosphere by absorbing and emitting solar radiation within the atmosphere, causing a greenhouse effect that warms the atmosphere and leads to global climate change. The main GHGs are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

*Heat density threshold* is a concentration of heat demand above which district energy systems are considered viable.

*Health* is defined as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity

*Heat pump* is a device that transfers heat energy from a source of heat to a target area by using mechanical energy.

*Heating Degree Days (HDD)* are calculated as how much colder the mean temperature at a location is than 18°C on a given day. For example, if a location experiences a mean temperature of 8°C on a certain day, there were 10 HDD (Heating Degree Days) that day because 18 - 8 = 10.

*HVAC* is heating, ventilation and air conditioning systems; referred to in the context of a building.

*Indicator* is an observable or measurable result that shows evidence of whether an impact has occurred and the nature of that impact. It provides a metric by which one can quantify and define the scale of a resulting change.

*Induced impacts* refer to impacts that arise further down the causal chain, as a result of indirect impacts (see definition above); examples might include additional spending by the people employed as a result of direct or indirect benefits.

*Light rail transit (LRT)* is a type of rapid transit that typically runs at street level in lanes that are separate from regular traffic.

*Marginal abatement cost (MAC) curves* are a visual (graphic) illustration of the results of model-based scenarios that convey both the economic

co-benefits (costs or savings) of an action or policy and the potential GHG reduction that can be achieved with the action or policy.

**Monetisation** is the attribution of financial value to phenomena, usually by relating a change in status of a good or service to the relevant market value of the good or service.

**Multi-criteria analysis** describes any structured approach used to determine overall preferences among alternative options. The actual measurement of indicators need not be in monetary terms, but are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria. Explicit recognition is given to the fact that a variety of both monetary and nonmonetary objectives may influence policy decisions.

**Multiplier effect** is a further extension of an induced impact, referring to ripple effects arising across the wider economy from the original energy efficiency policy. For example, a multiplier effect would be that stores, restaurants or other service providers benefit from the spending of people who are newly employed (directly or indirectly) because of an energy efficiency policy and have greater capacity to spend or invest their earnings.

**Net benefit** is the measure of the value of an outcome after the cost of delivering the outcome has been accounted for and deducted.

**Re-commissioning** is a process of examining how a building's operating and maintenance systems are functioning and optimising these systems after a building has been fully operational for a period of time.

**Renewable natural gas** is natural gas that is generated from resources which are naturally replenished on a human timescale, such as solid waste.

**Renewable energy** is energy that comes from resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat.

**Sankey** is a type of diagram that illustrates the flow of materials, often energy, through a system.

**Sick building syndrome** is a situation in which the occupants of a building experience acute health- or comfort-related effects that seem to be linked directly to the time spent in the building.

*Social capital* is the links, shared values and understandings in society that enable individuals and groups to trust each other and so work together

*Social equity* implies fair access to livelihood, education, and resources; full participation in the political and cultural life of the community; and self-determination in meeting fundamental needs.

*Solar photovoltaic*, also known as solar electric systems or solar panels, these are systems that convert sunlight into electricity. Any excess electricity produced that a building does not use can be sold to the utility through a process called net-metering.

*Solar thermal* is a system that uses solar energy to generate hot water that can be used for domestic hot water and/or space heating in buildings. The system can be paired with thermal energy storage that can store heat until it is needed to meet demand.

*Wedge* is a representation of GHG emissions reductions resulting from a particular action or policy measured against a business as usual curve.

*Well-being* refers to the integrated physiological, psychological and mental state of an individual, a household or group of people. It is broader than health, which typically refers to the physical state of an individual, family or group of people (public health).

*Vehicle kilometres travelled* is a measurement of kilometres traveled by vehicles within a specified region for a specified time period.

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