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.

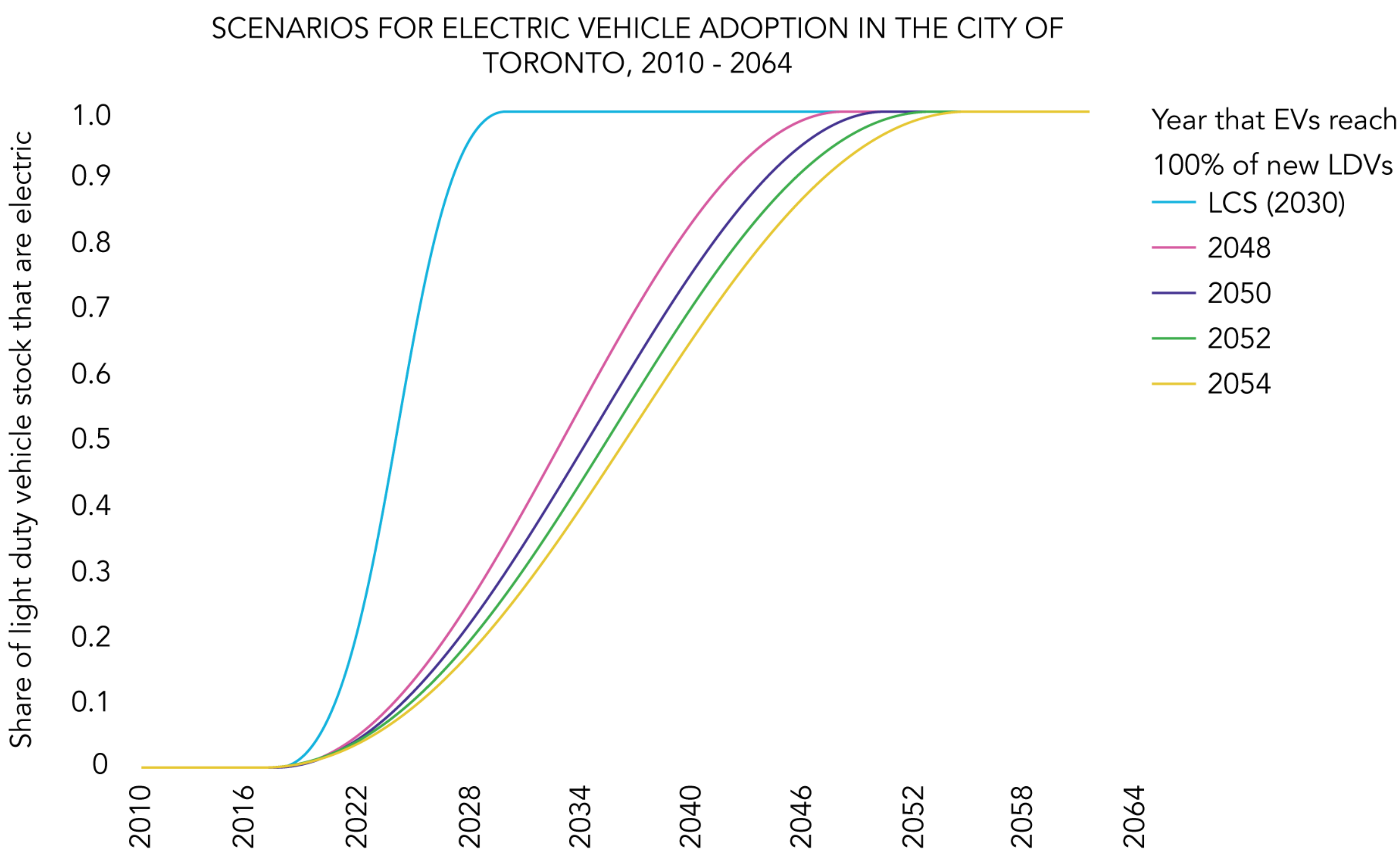

Figure 23. Electric vehicle adoption rate

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.

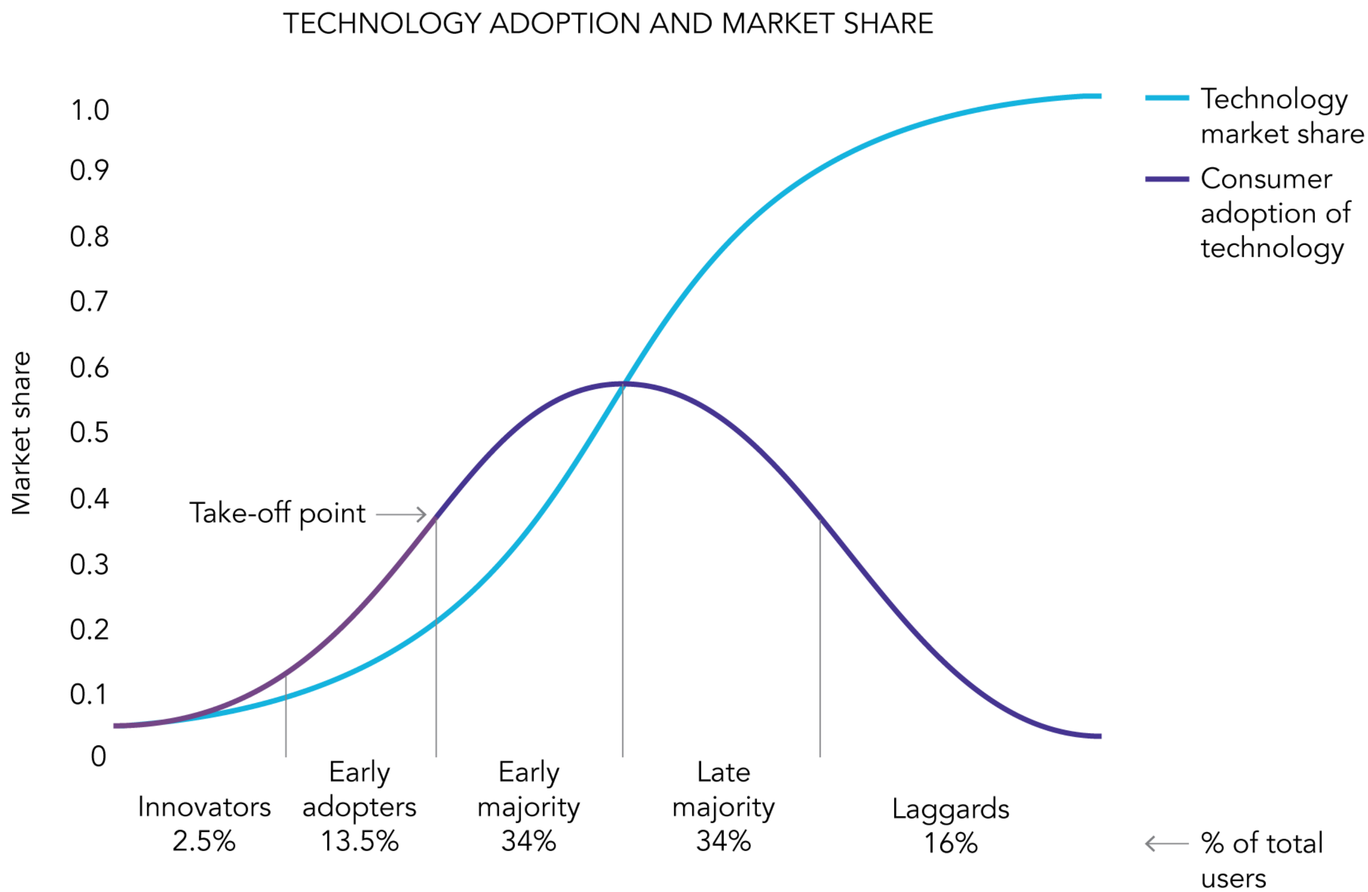

Figure 24. The S curve

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]

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

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.

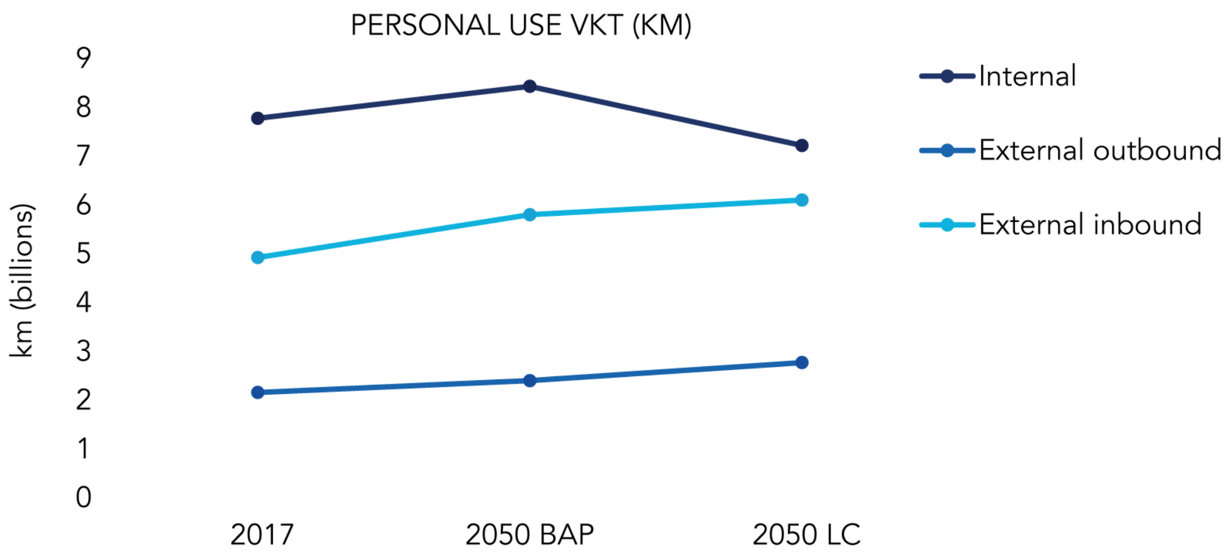

Figure 25. Personal use VKT.

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

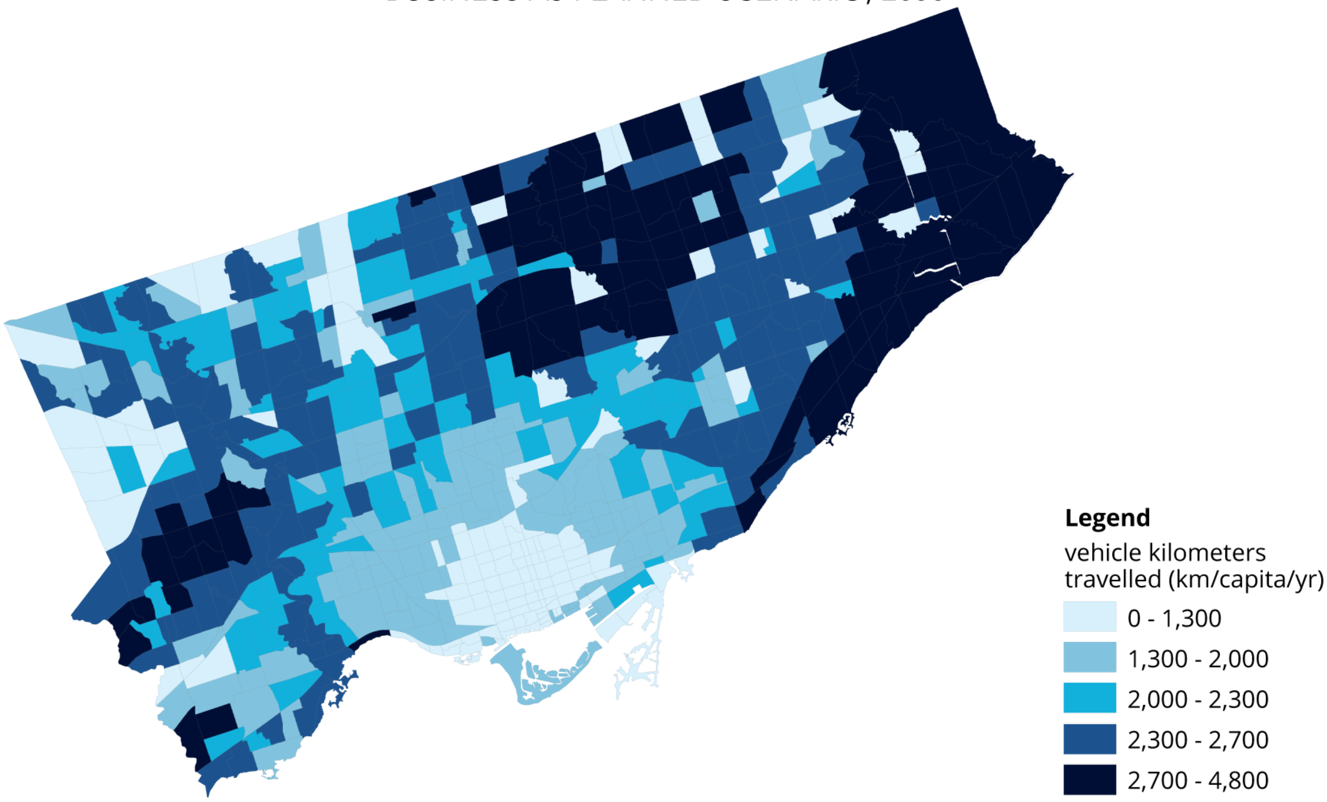

Figure 26. Home-based VKT per capita by zone, BAP 2050.

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

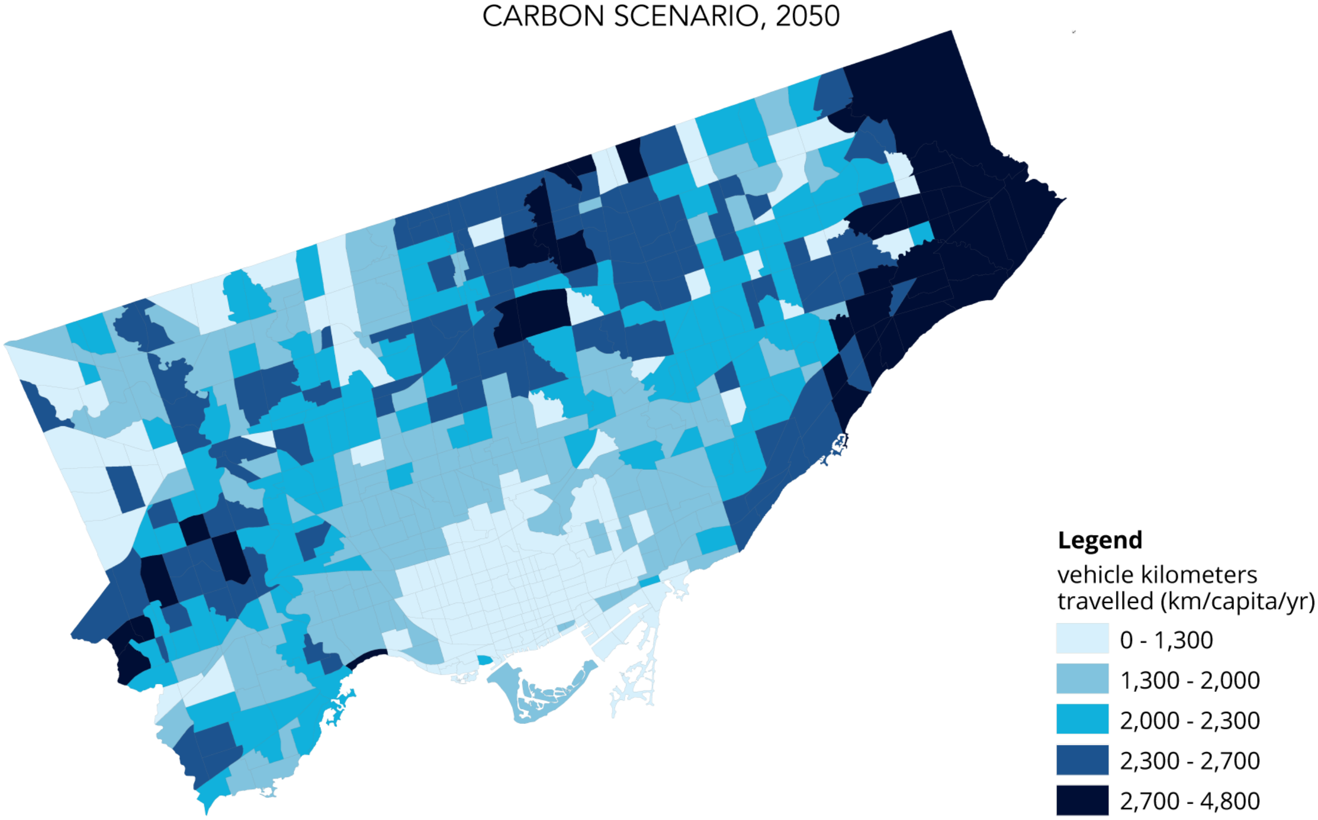

Figure 27. Home-based VKT per capita by zone, LCS 2050.

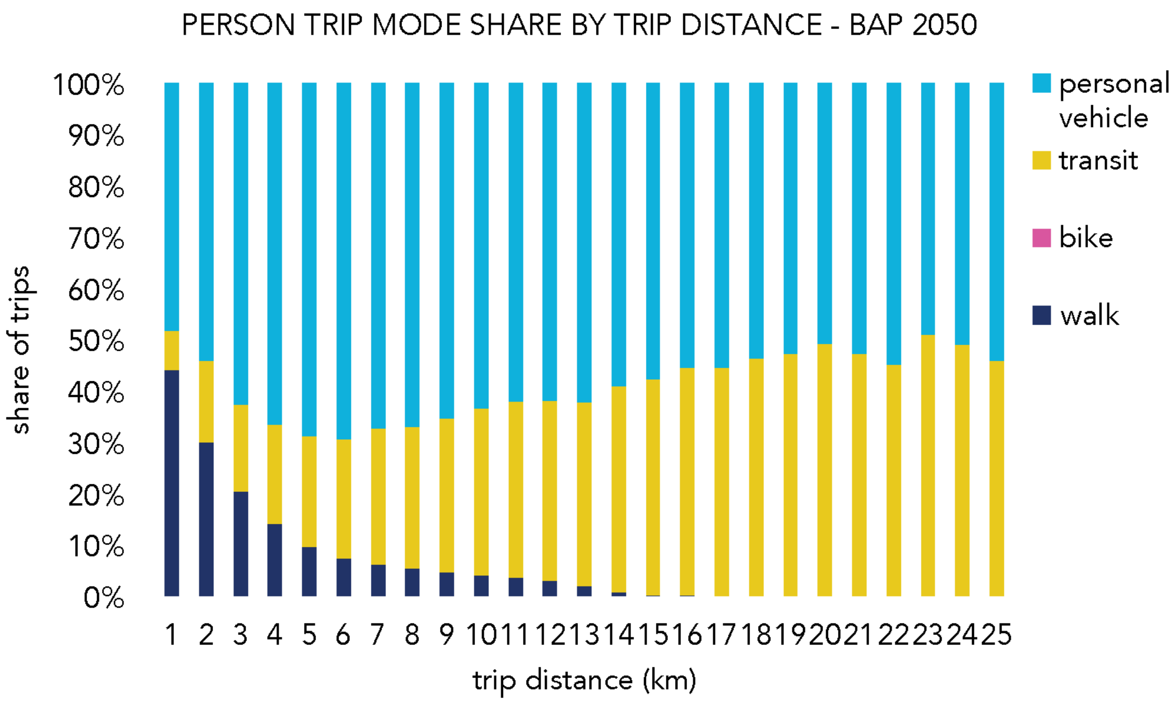

Figure 28. Person trip mode share by distance, BAP 2050.

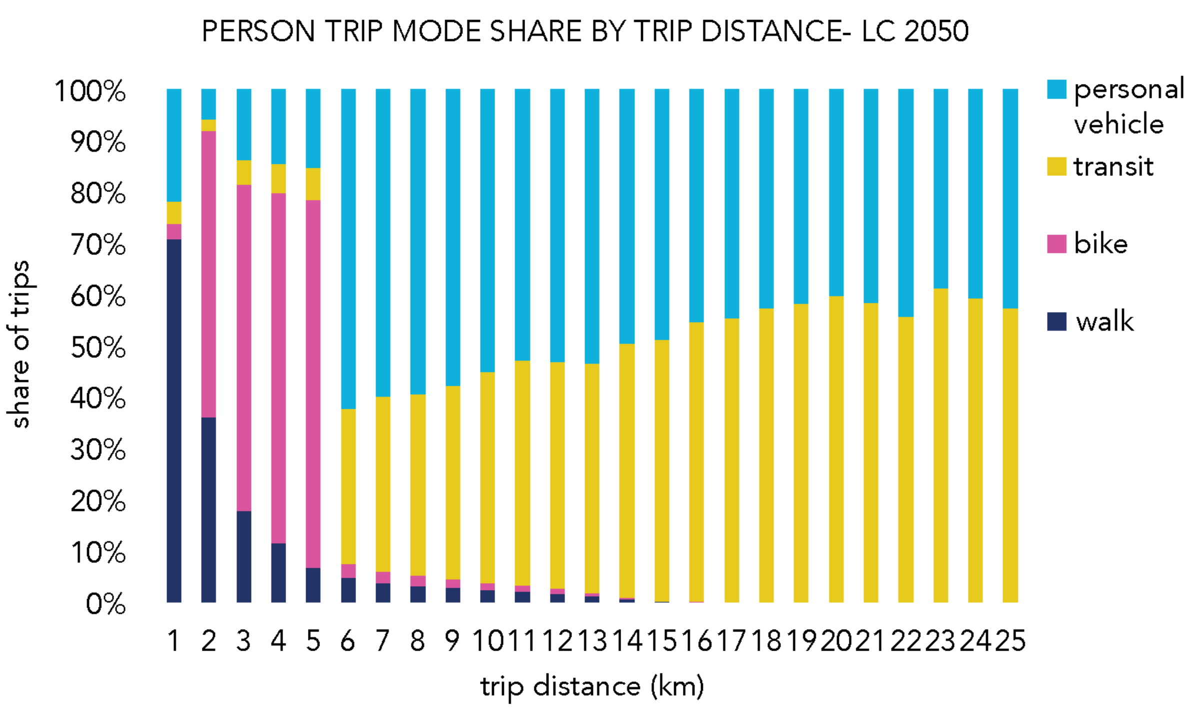

Figure 29. Person trip mode share by distance, Low Carbon 2050.

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.

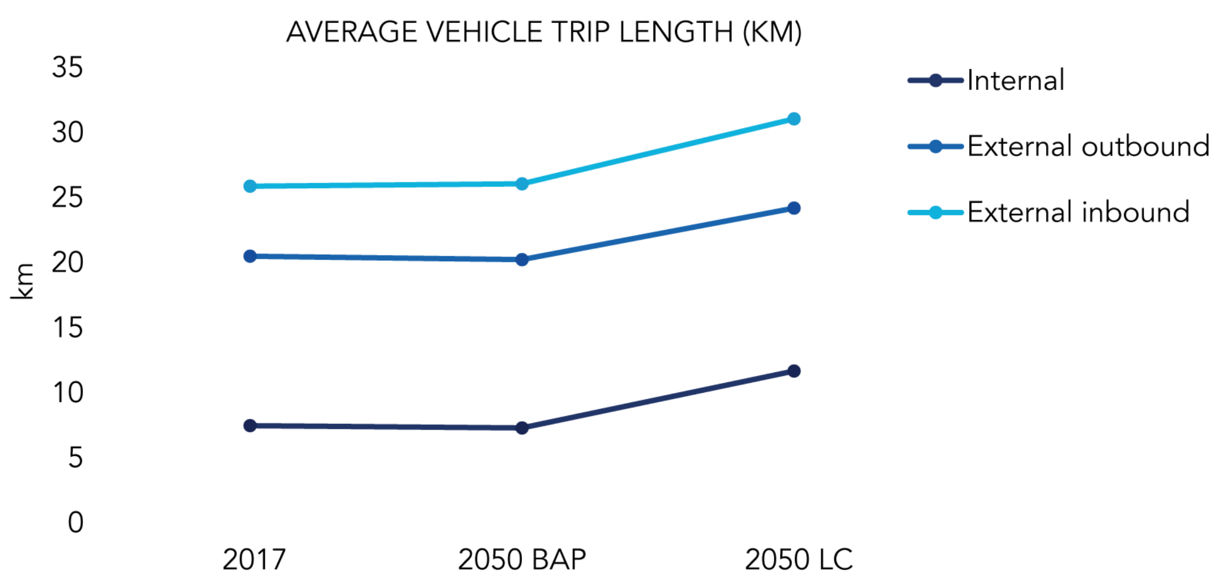

Figure 30. Average vehicle trip length.

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.

397A
5
4
4

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: 17-1: deepwater cooling 17-2: captured waste heat 17-3: geothermal	428 109 143 176
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.

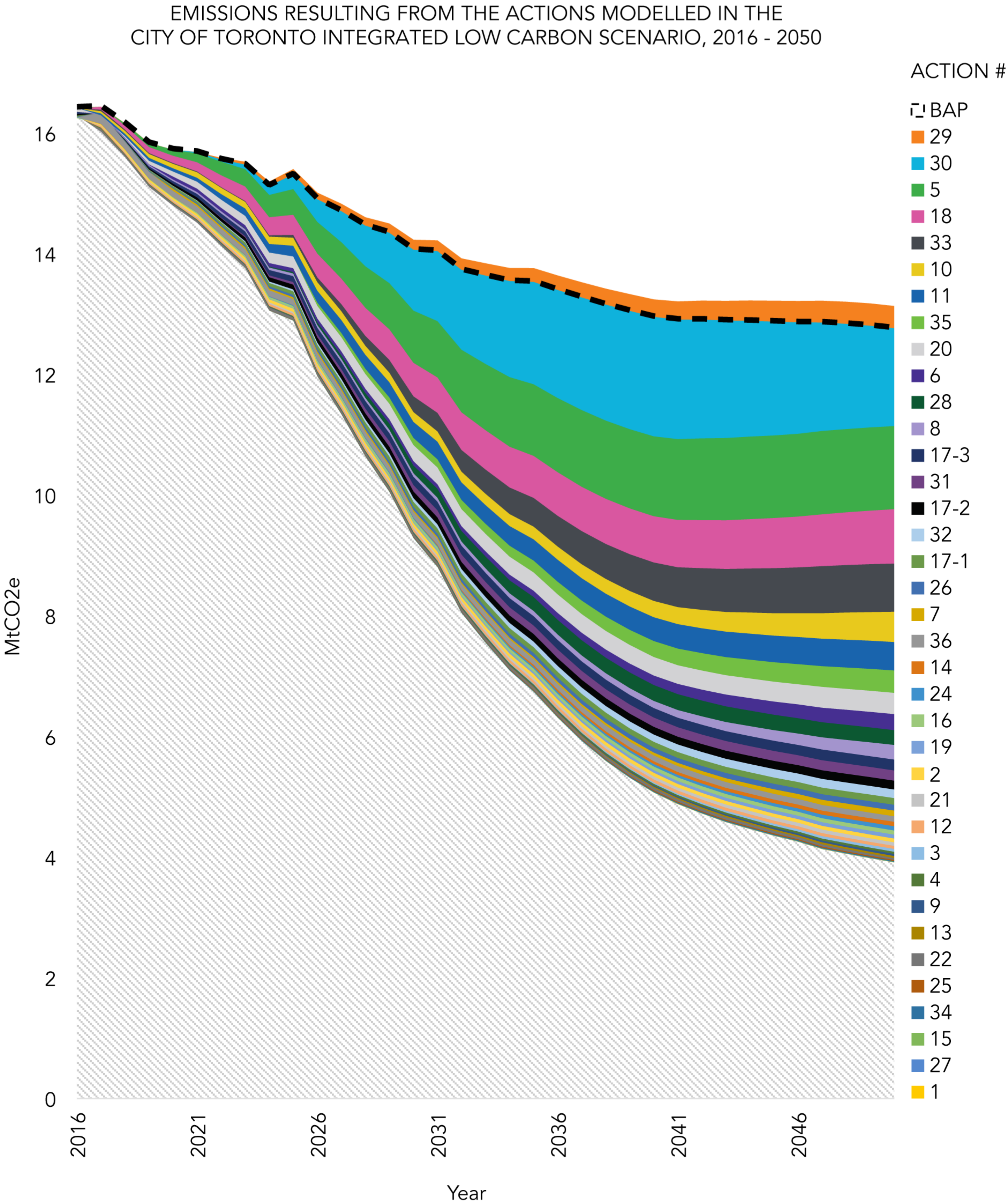

Figure 31. Wedges diagram for the low carbon scenario

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.

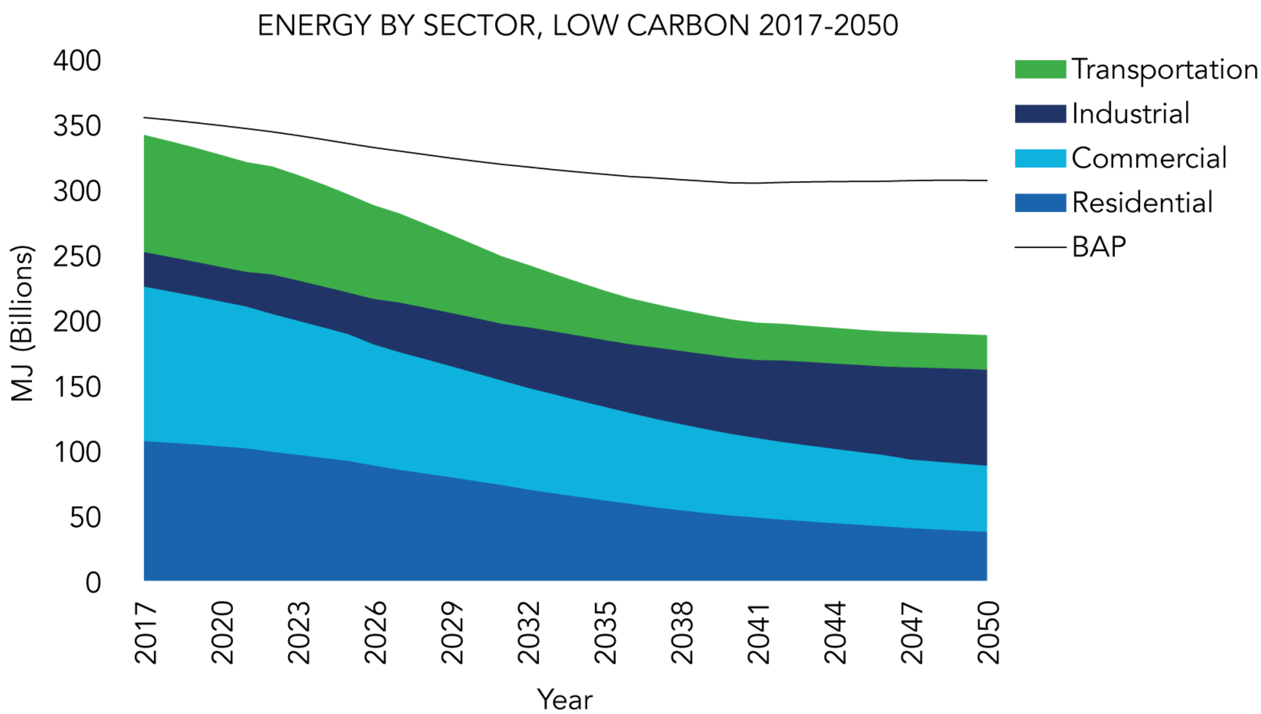

Figure 32. Energy by sector, Low Carbon 2017-2050.

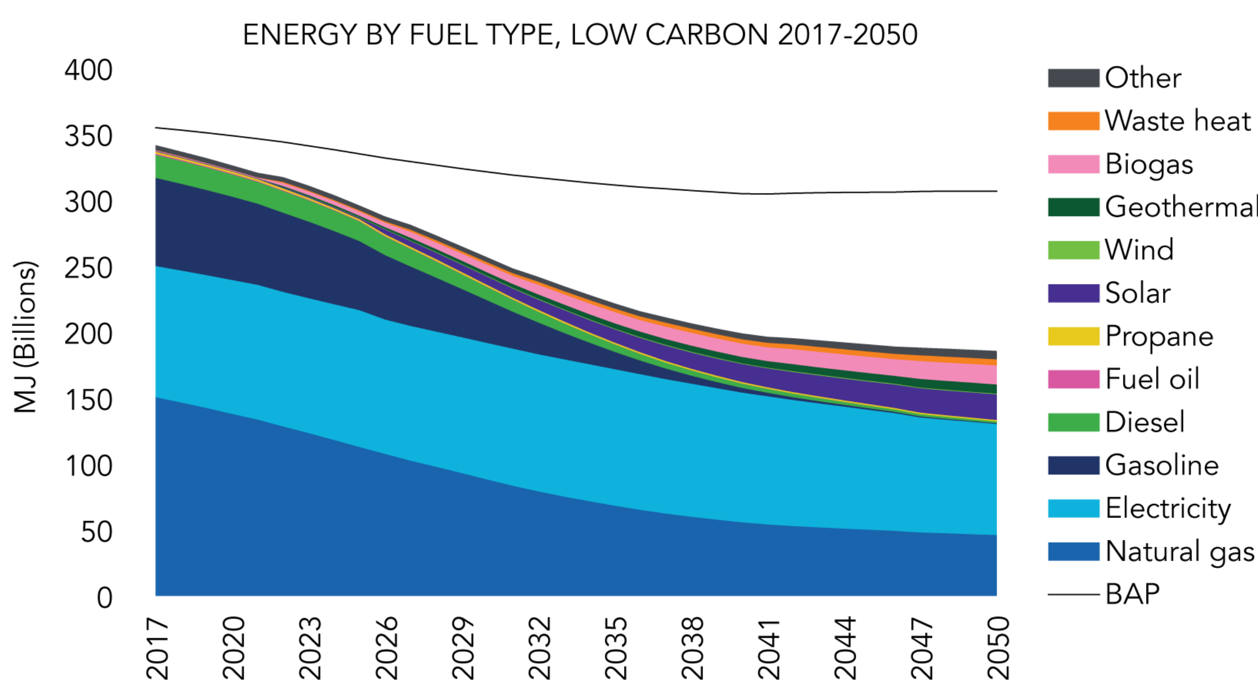

Figure 33. Energy by fuel, Low Carbon 2017-2050.

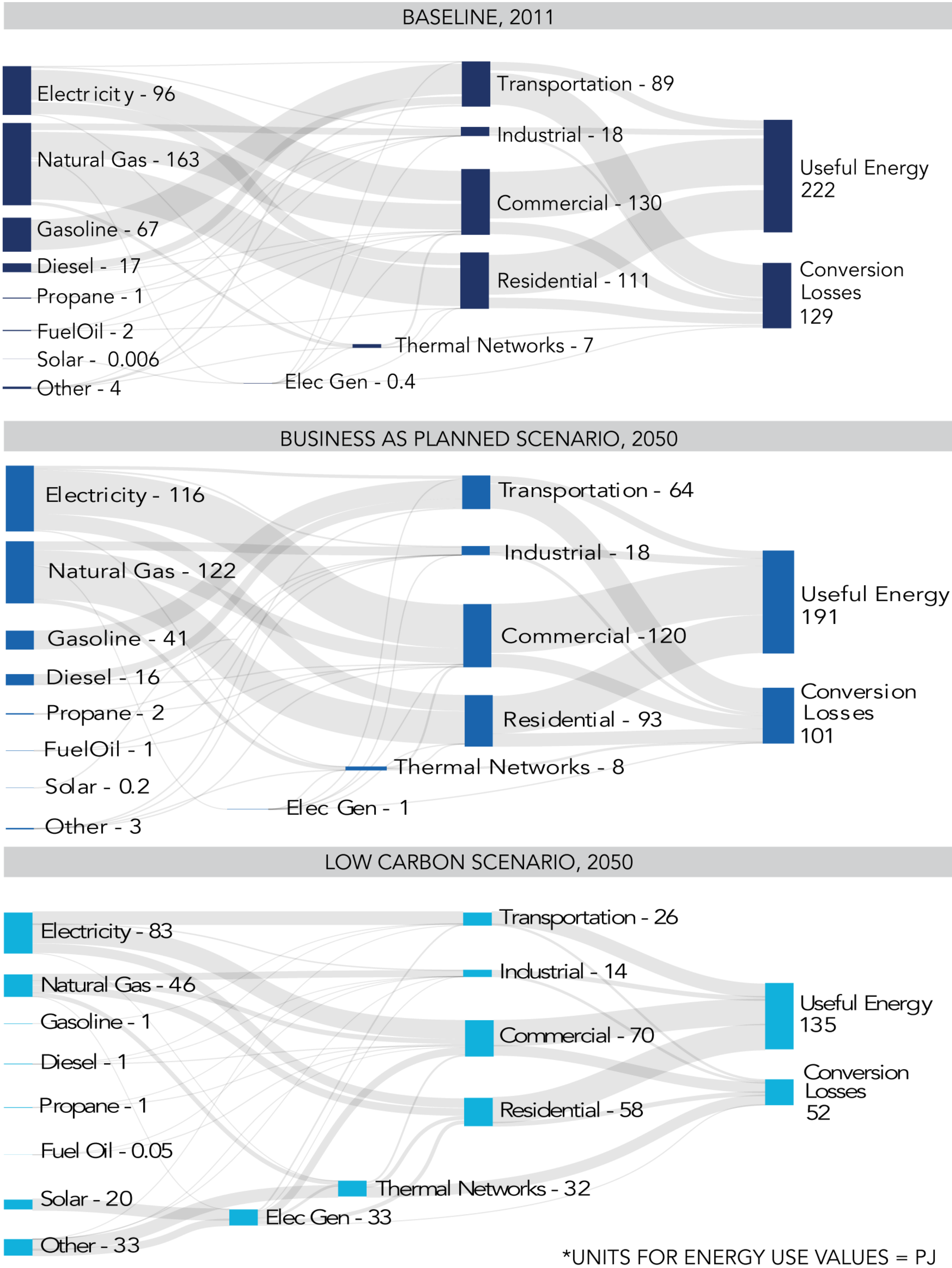

Figure 34. Sankey, Baseline, BAP, and LCS.

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

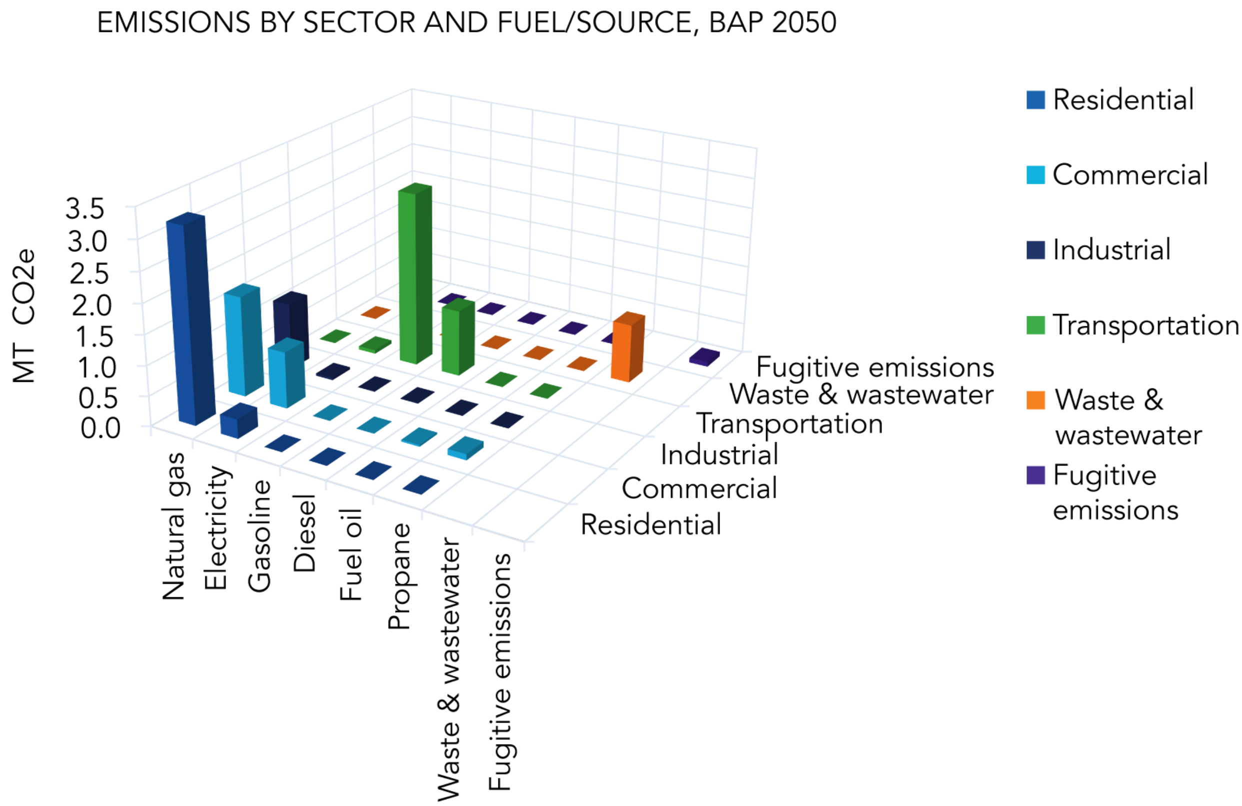

Figure 35. Emissions by sector and fuel, BAP 2050.

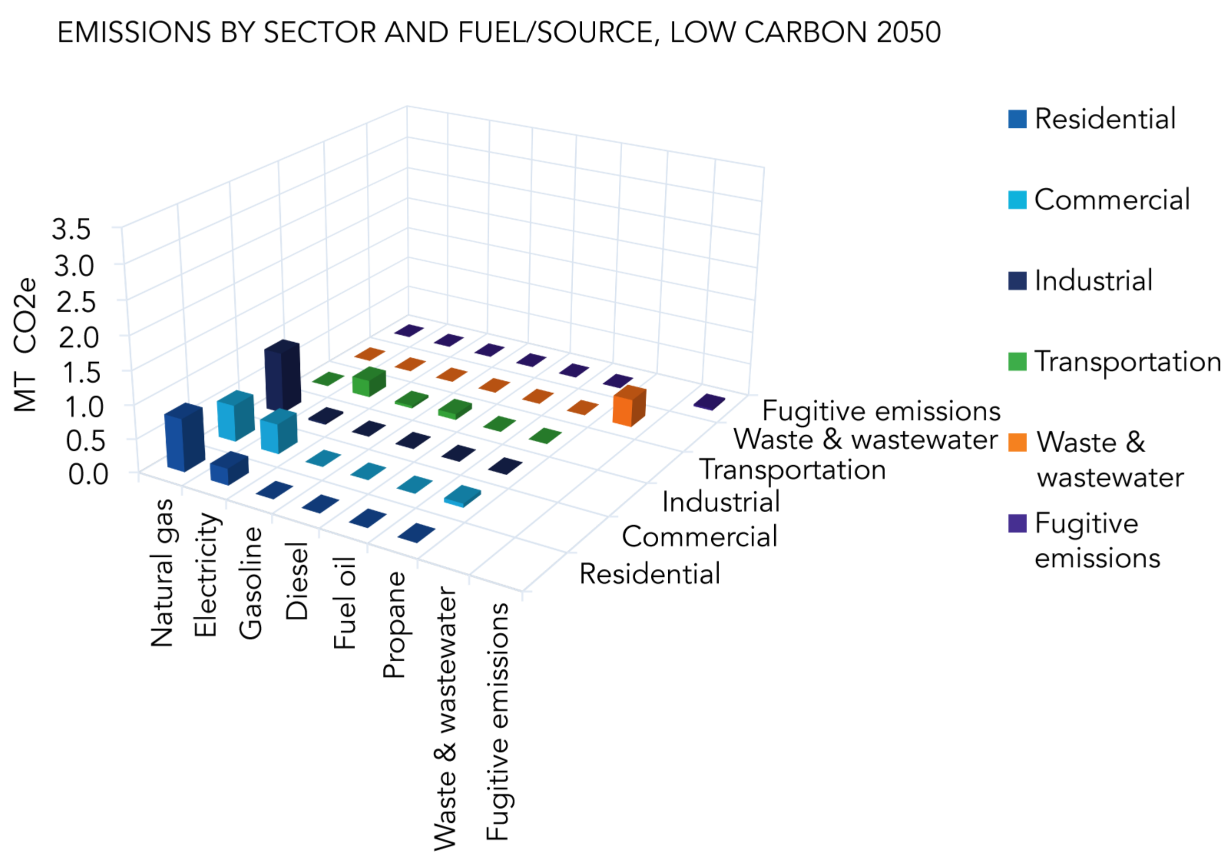

Figure 36. Emissions by sector and fuel, Low Carbon 2050.

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.


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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.

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.

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-BENEFITS/ CO-HARMS	IMPACT OVERVIEW	LAND-USE	BUILDINGS	TRANSPORTATION	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-BENEFITS/ CO-HARMS	IMPACT OVERVIEW	LAND-USE	BUILDINGS	TRANSPORTATION	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-BENEFITS/ CO-HARMS	IMPACT OVERVIEW	LAND-USE	BUILDINGS	TRANSPORTATION	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-BENEFITS/ CO-HARMS	IMPACT OVERVIEW	LAND-USE	BUILDINGS	TRANSPORTATION	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.

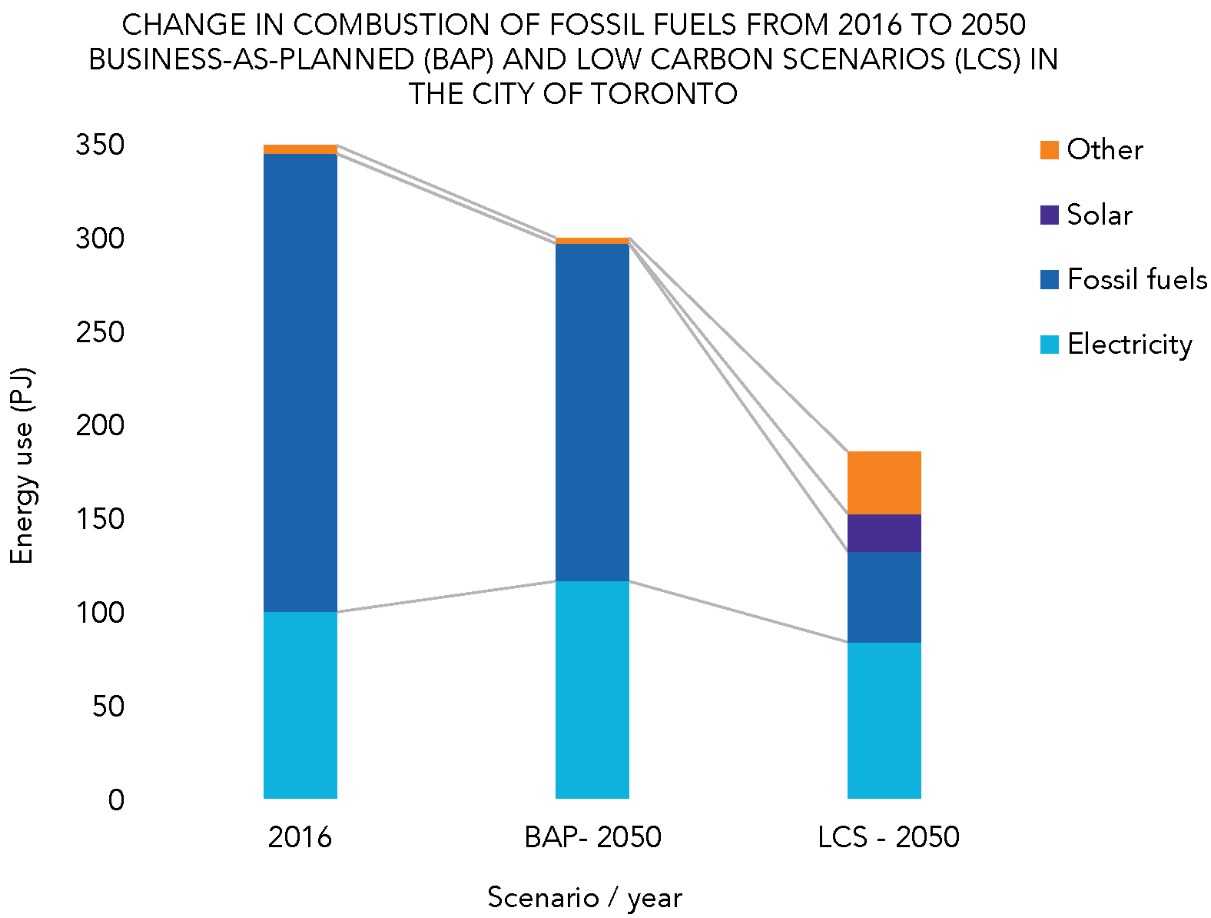

Figure 37. Fossil fuels as a share of energy consumed.

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.

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

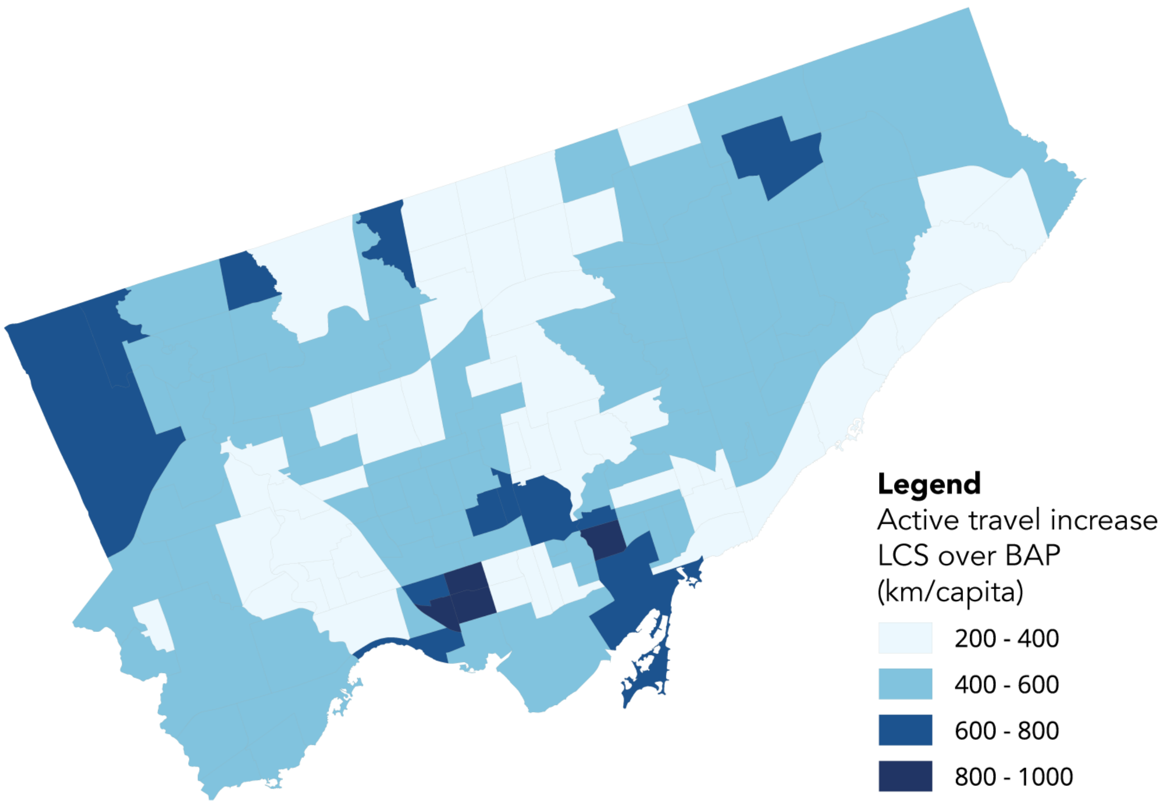

Figure 38. Increase in km of active transportation in the LCS over BAP by neighbourhood.

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

INCREASE IN KILOMETERS OF YEARLY ACTIVE TRAVEL (WALKING AND CYCLING) IN THE LOW CARBON SCENARIO (LCS) OVER BUSINESS AS PLANNED (BAP) SCENARIO, 2050

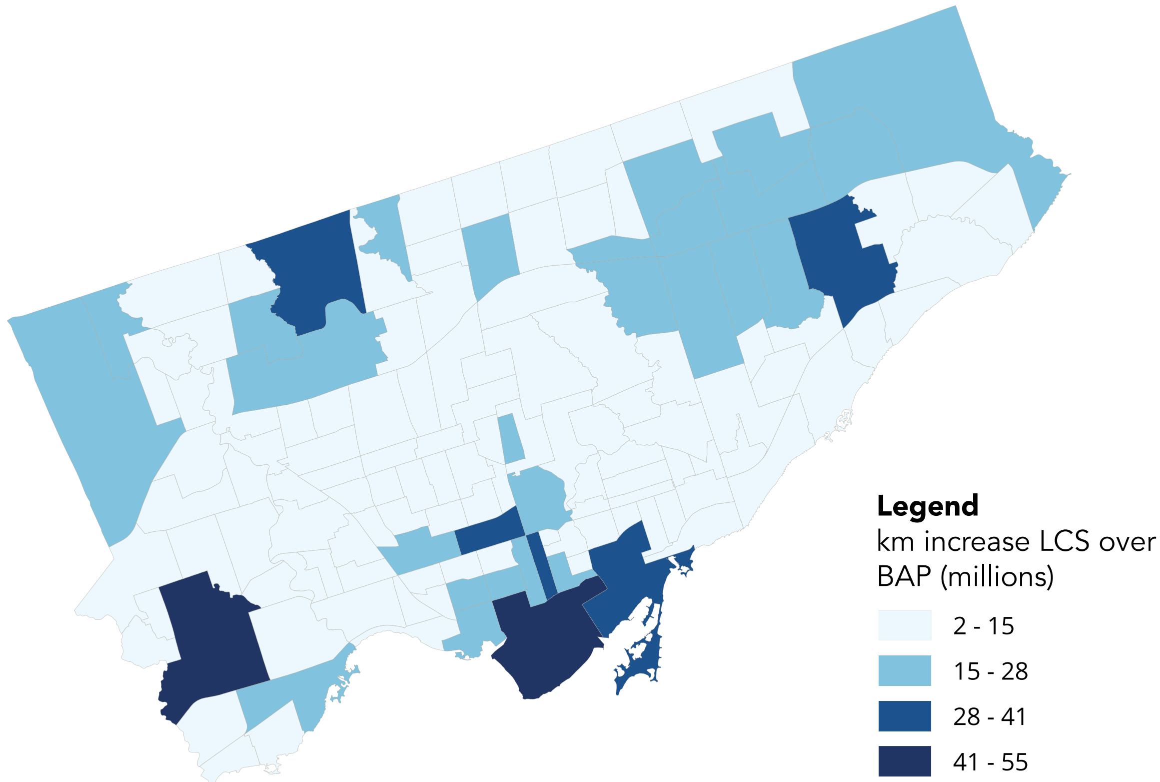

Figure 39. Increase in walking cycling km in LCS over BAP by neighbourhood.

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

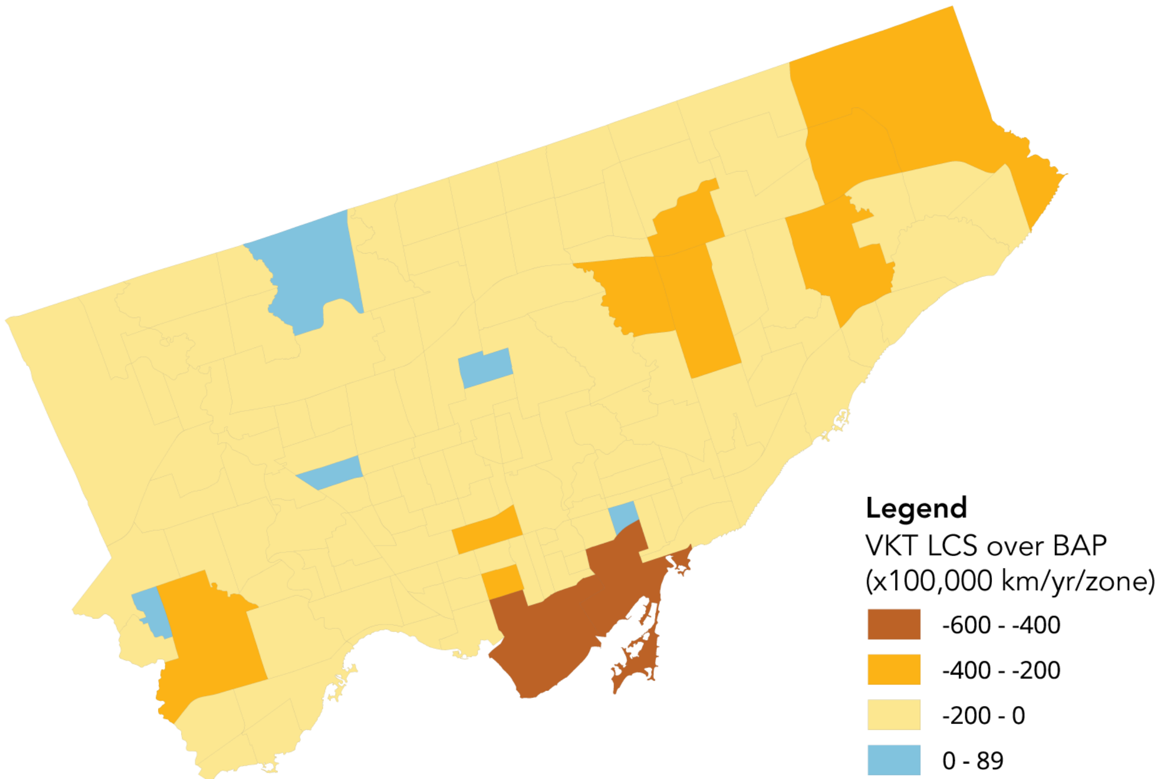

Figure 40. Increase/decrease in VKT by zone of LCS over BAP.

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

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

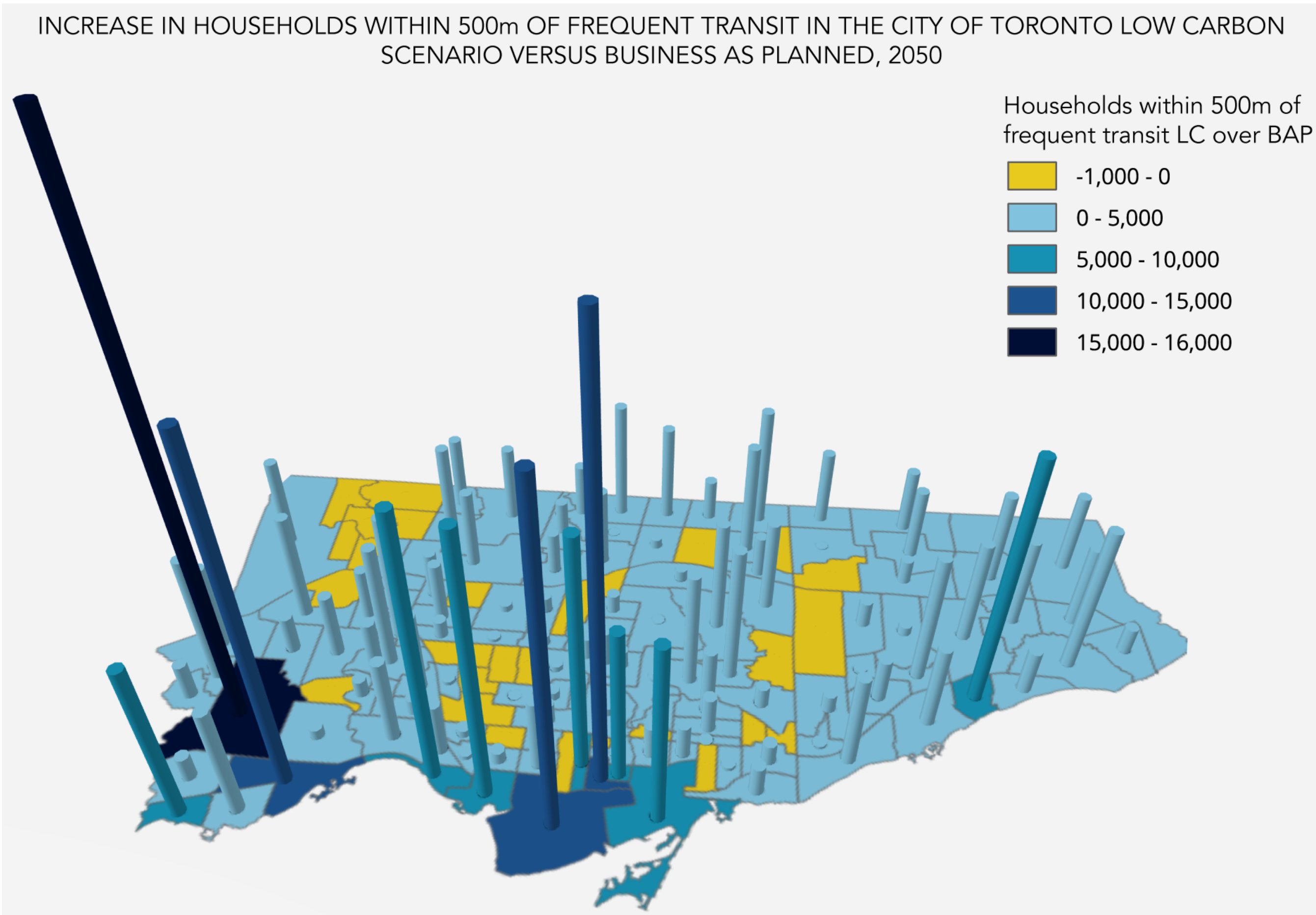

Figure 41. Change in dwelling units within 500m of transit in the LCS over the BAP.

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

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/16815378/2007/00002007/00000001/0107101ec007

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

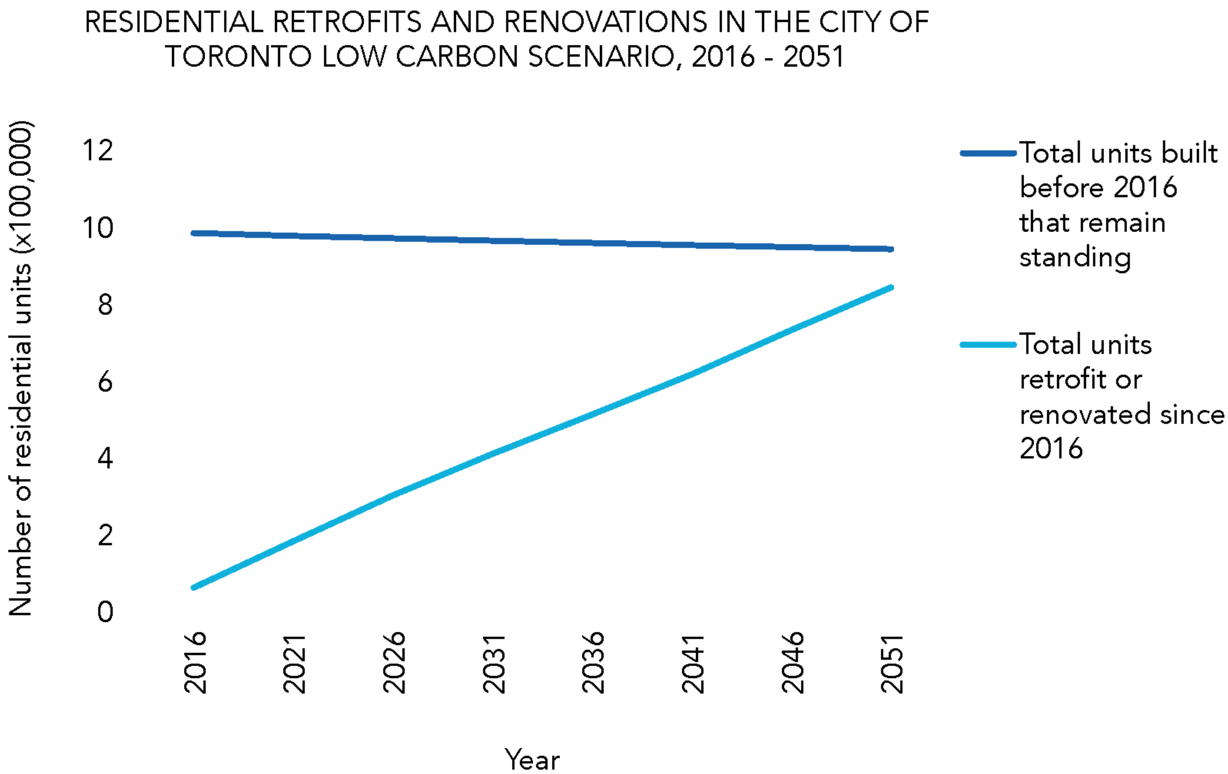

Figure 42. Number of units retrofit by 2050 in the LCS.

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]

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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

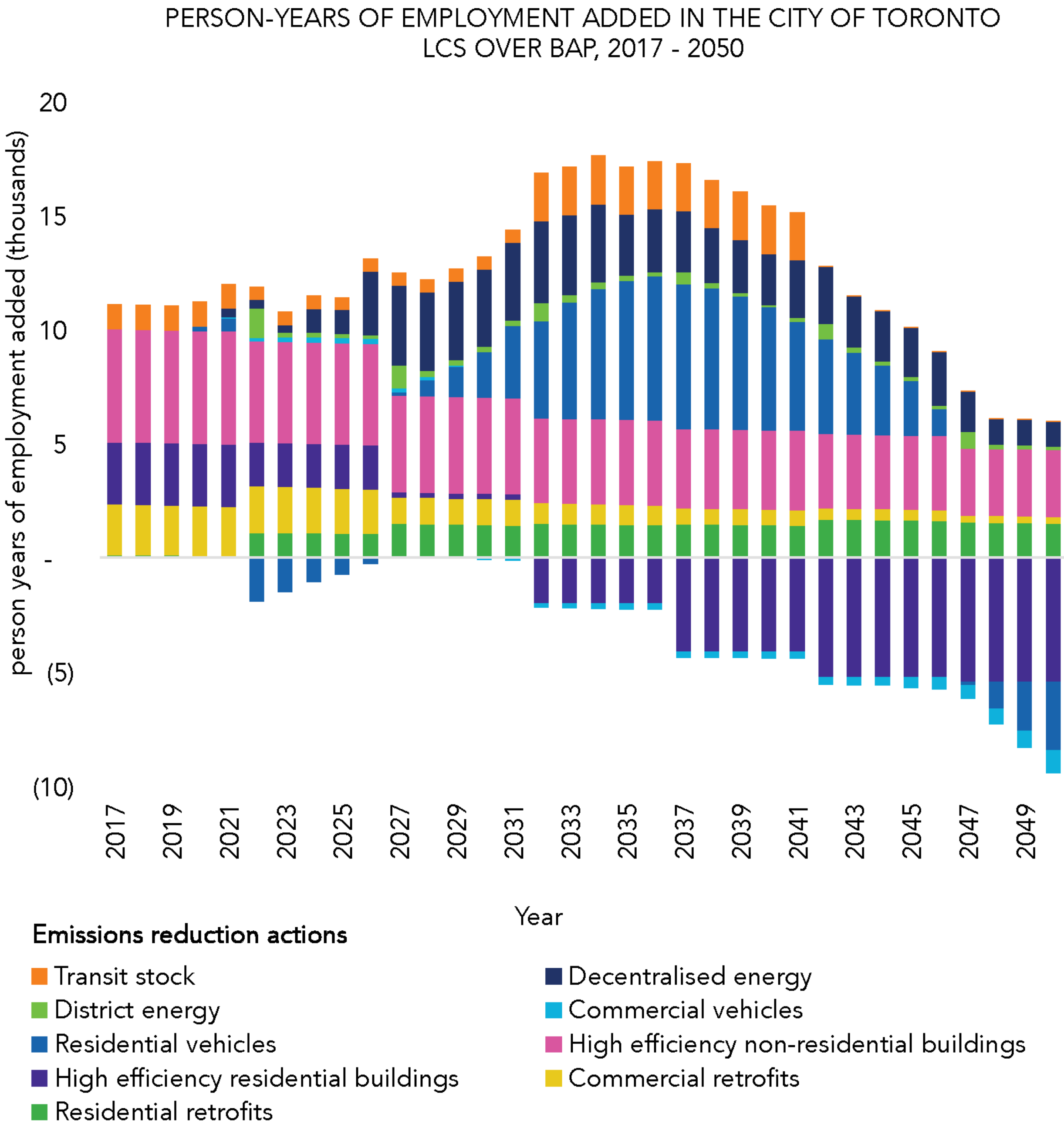

Figure 43. Additional person-years of employment associated with the LCS

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

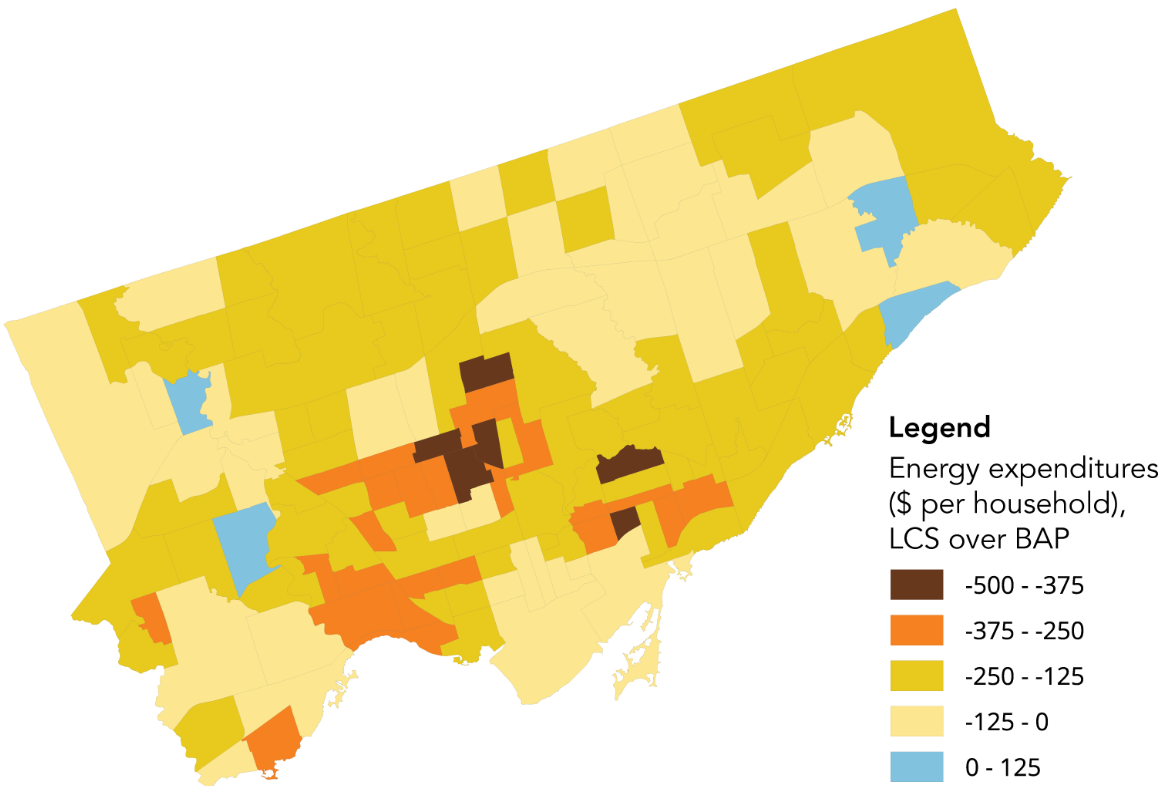

Figure 44. Change in household energy expenditures of LCS over BAP.

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

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

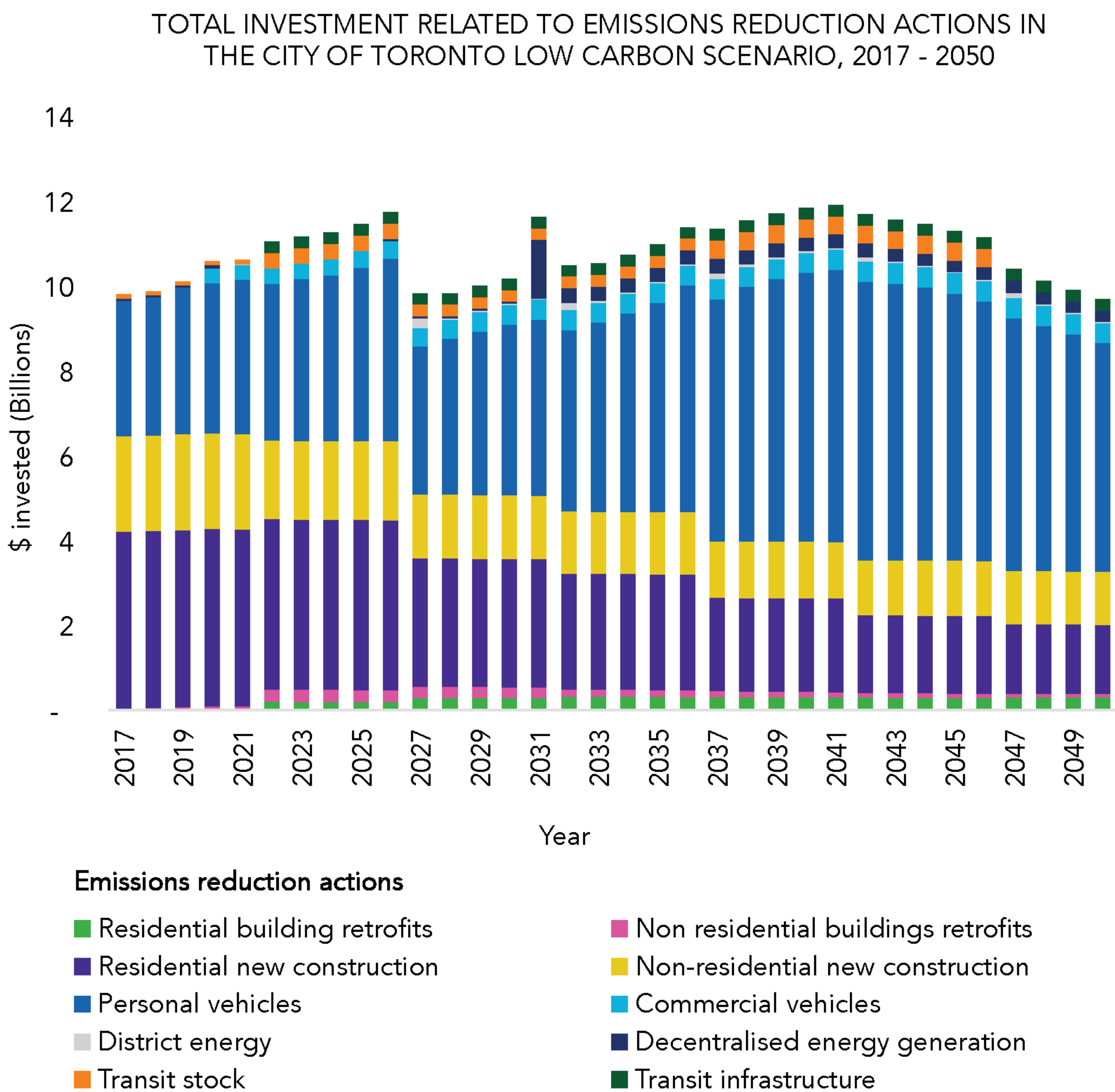

Figure 45. Total investment in the LCS

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]

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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

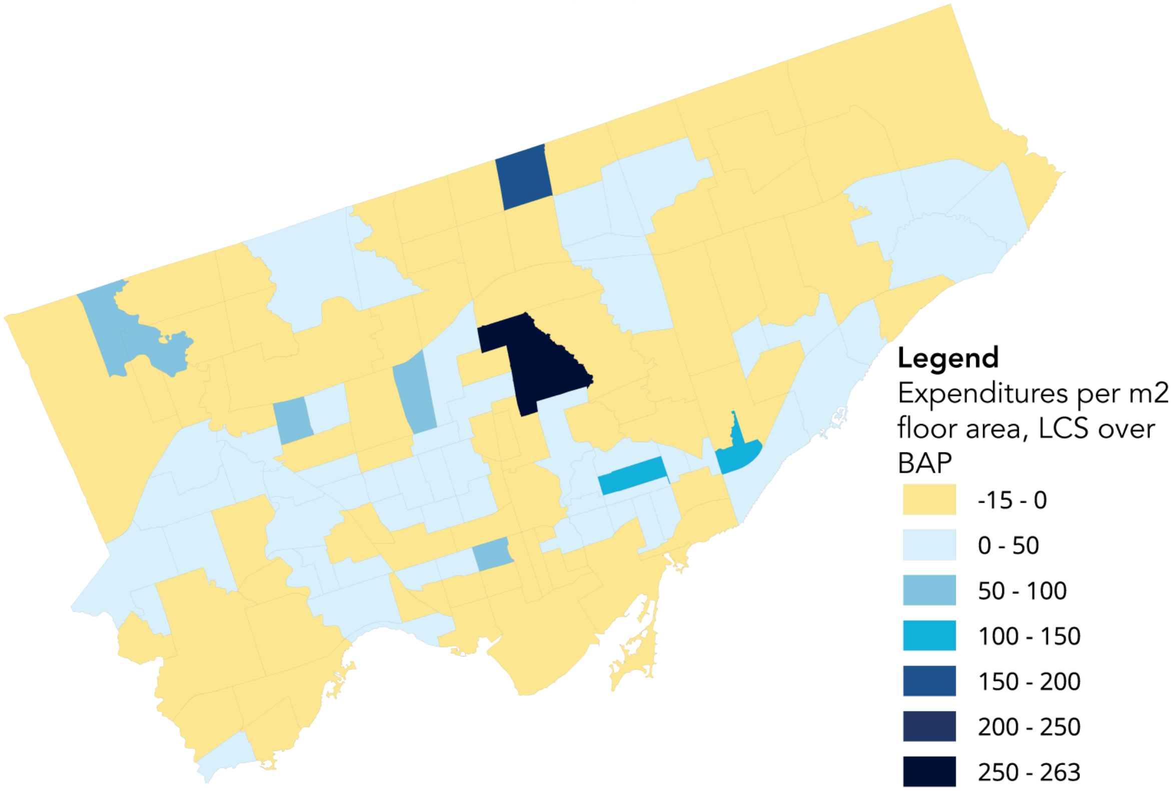

Figure 46. Impact on energy costs for commercial/industrial floor space of LCS over BAP by zone.

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.

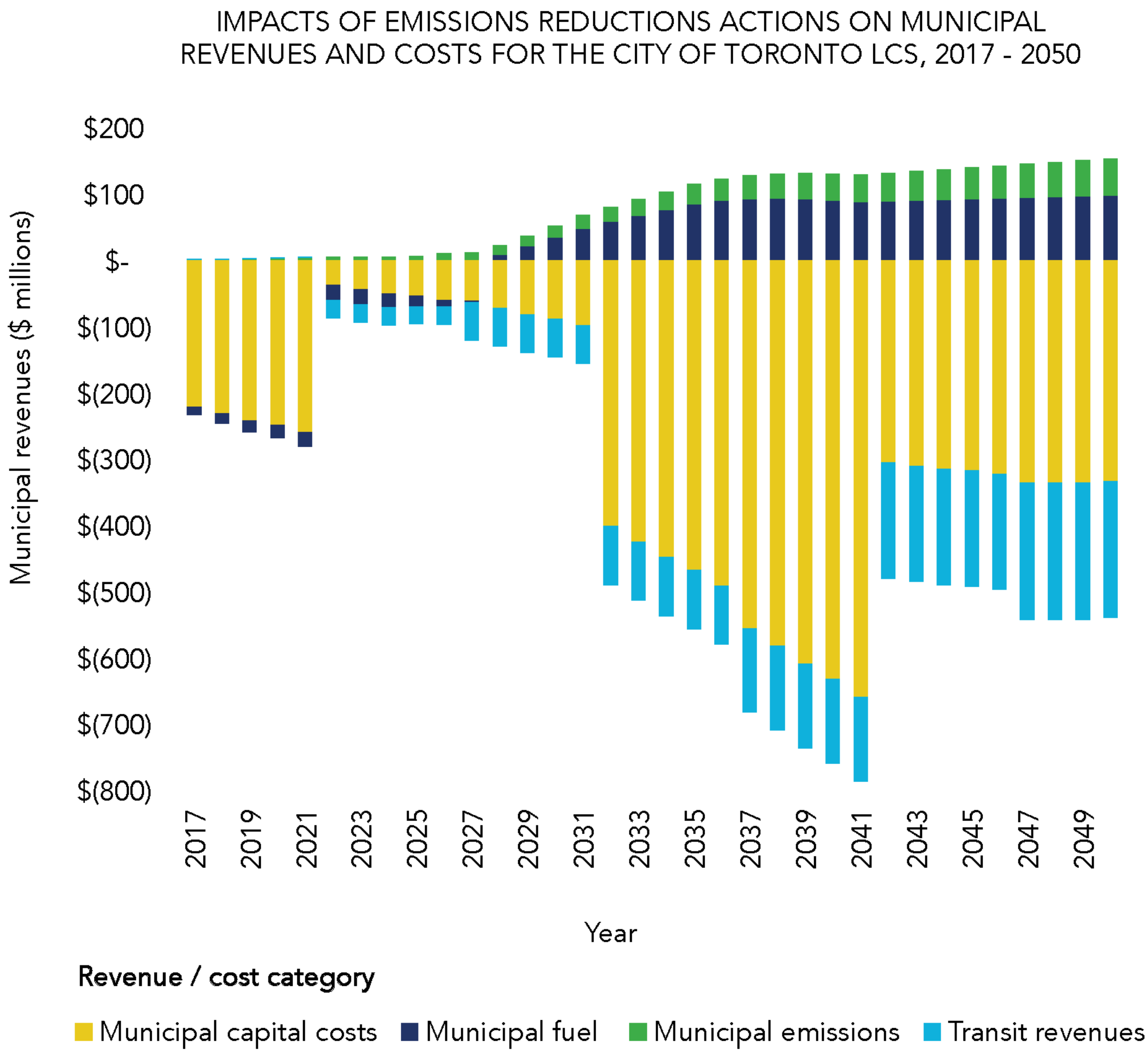

Figure 47. Financial implications for municipal expenditures

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.

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

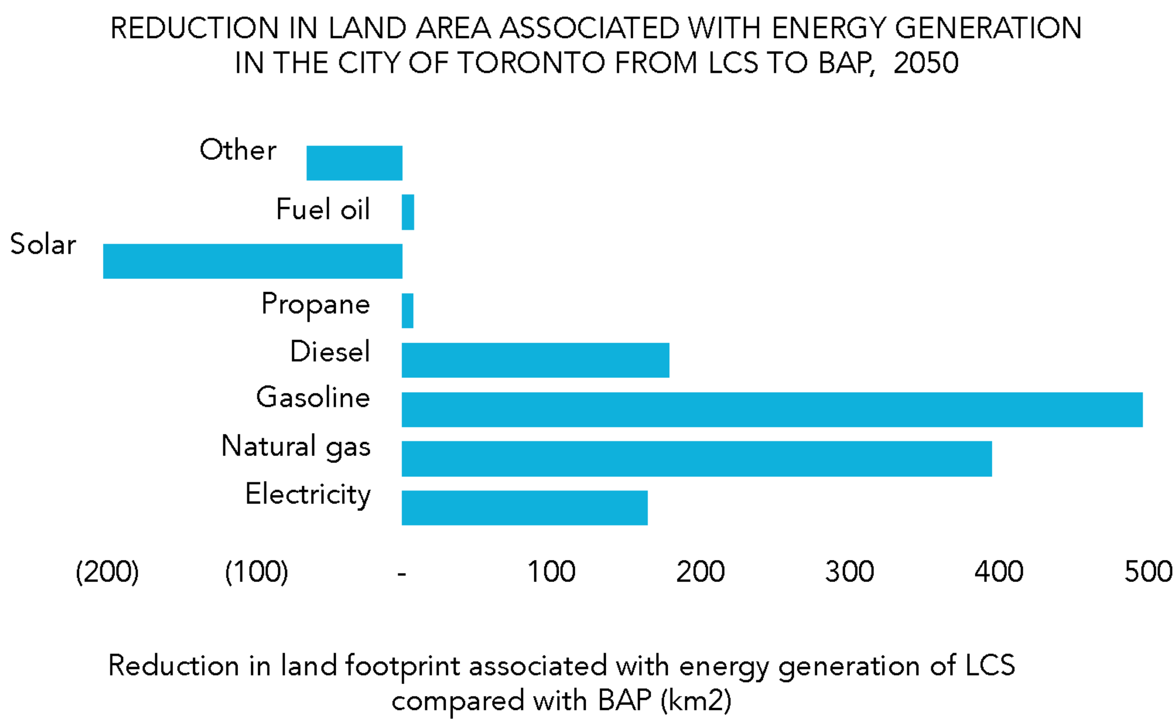

Figure 48. Reduced energy sprawl as a result of the low carbon scenario

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.

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.

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

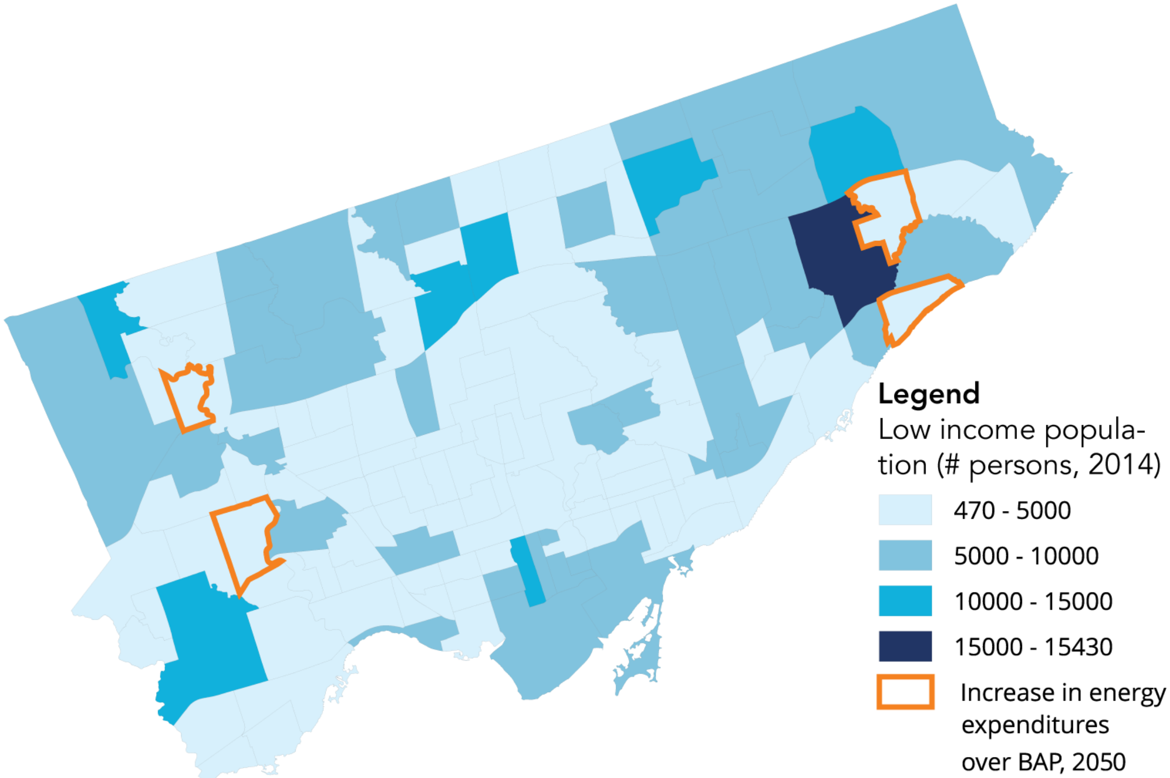

Figure 49. Impact of energy cost increases/decreases for housing of the LCS over BAP in vulnerable neighbourhoods.

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

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%20Update%20to%20Environment%20and%20Climate%20Change%20Canadas%20Social%20Cost%2

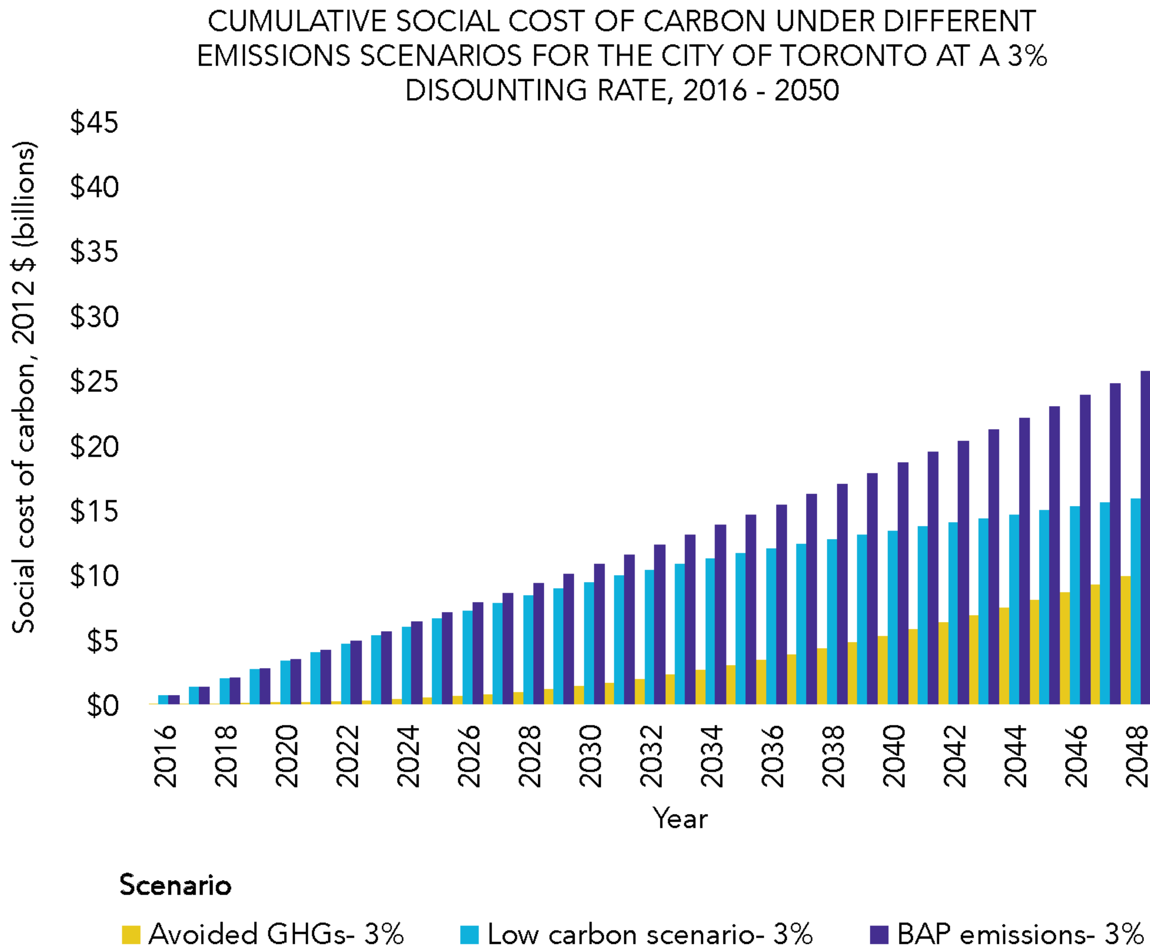

Figure 50. Global[119] social cost of carbon, in $2012 cumulative at a 3% discounting rate

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.

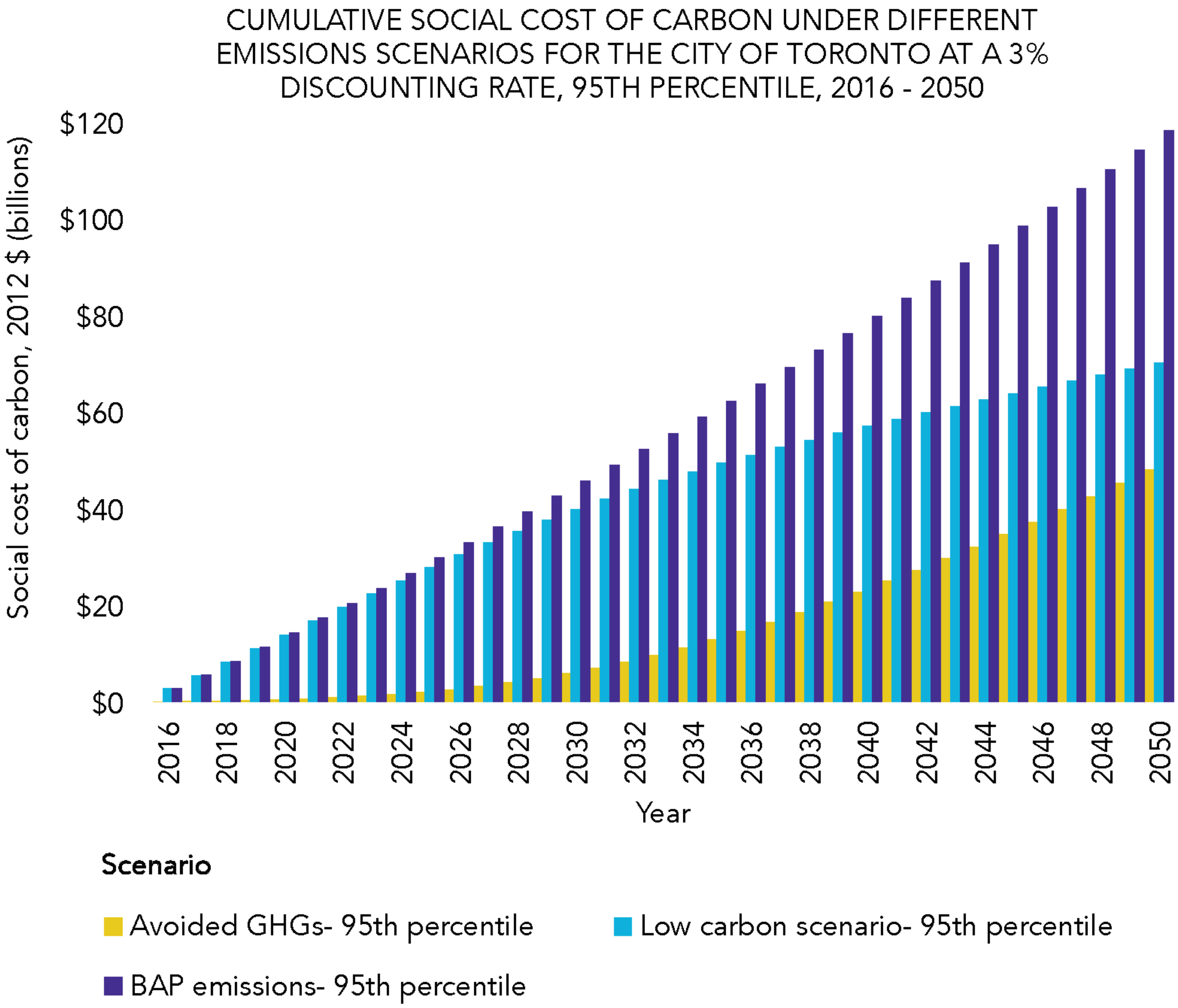

Figure 51. Global social cost of carbon, in $2012 cumulative at a 3% discounting rate, 95th percentile

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.

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.

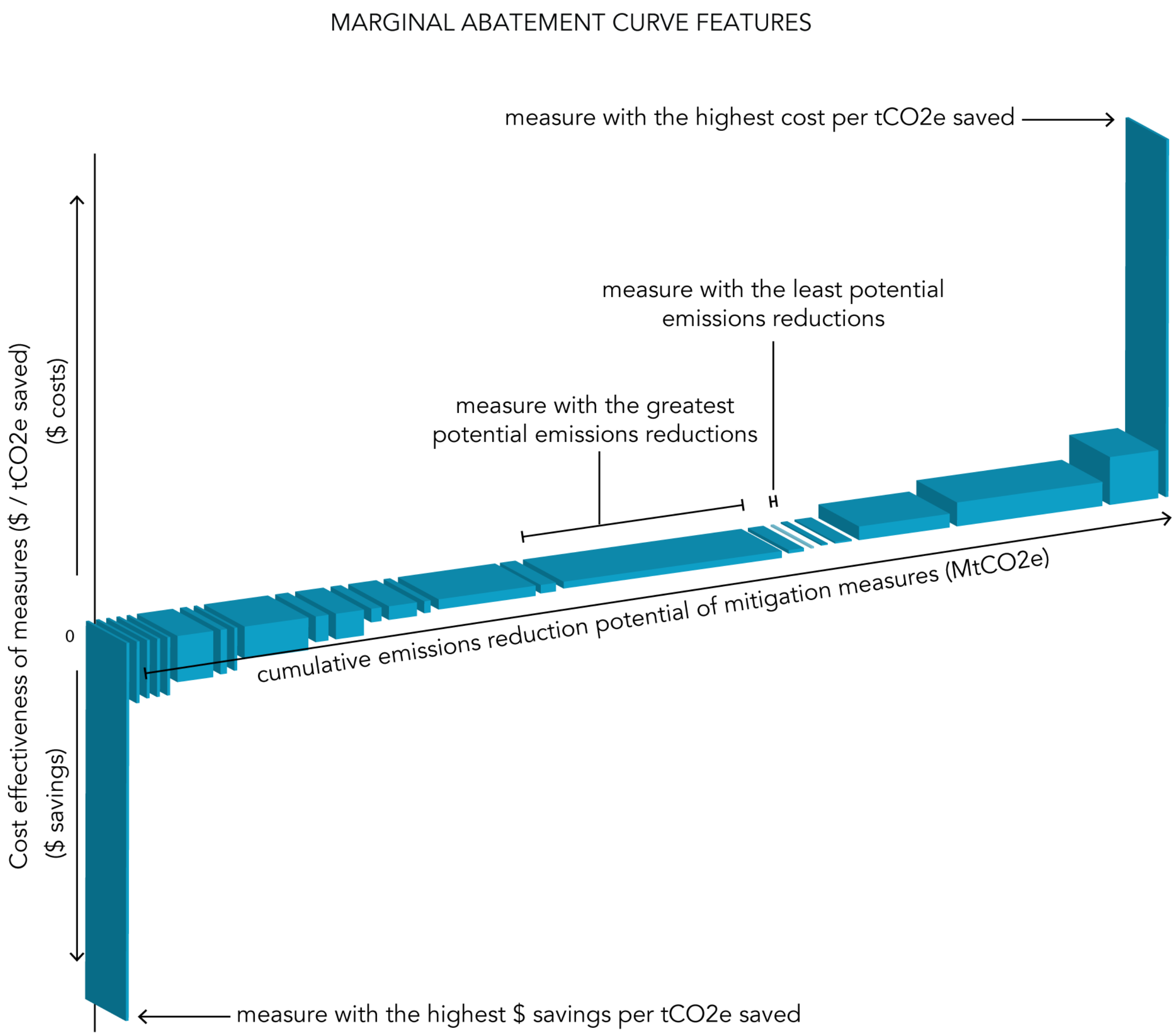

Figure 52. Marginal Abatement Curve components

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.

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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 I TOTAL kt CO2e SAVED)

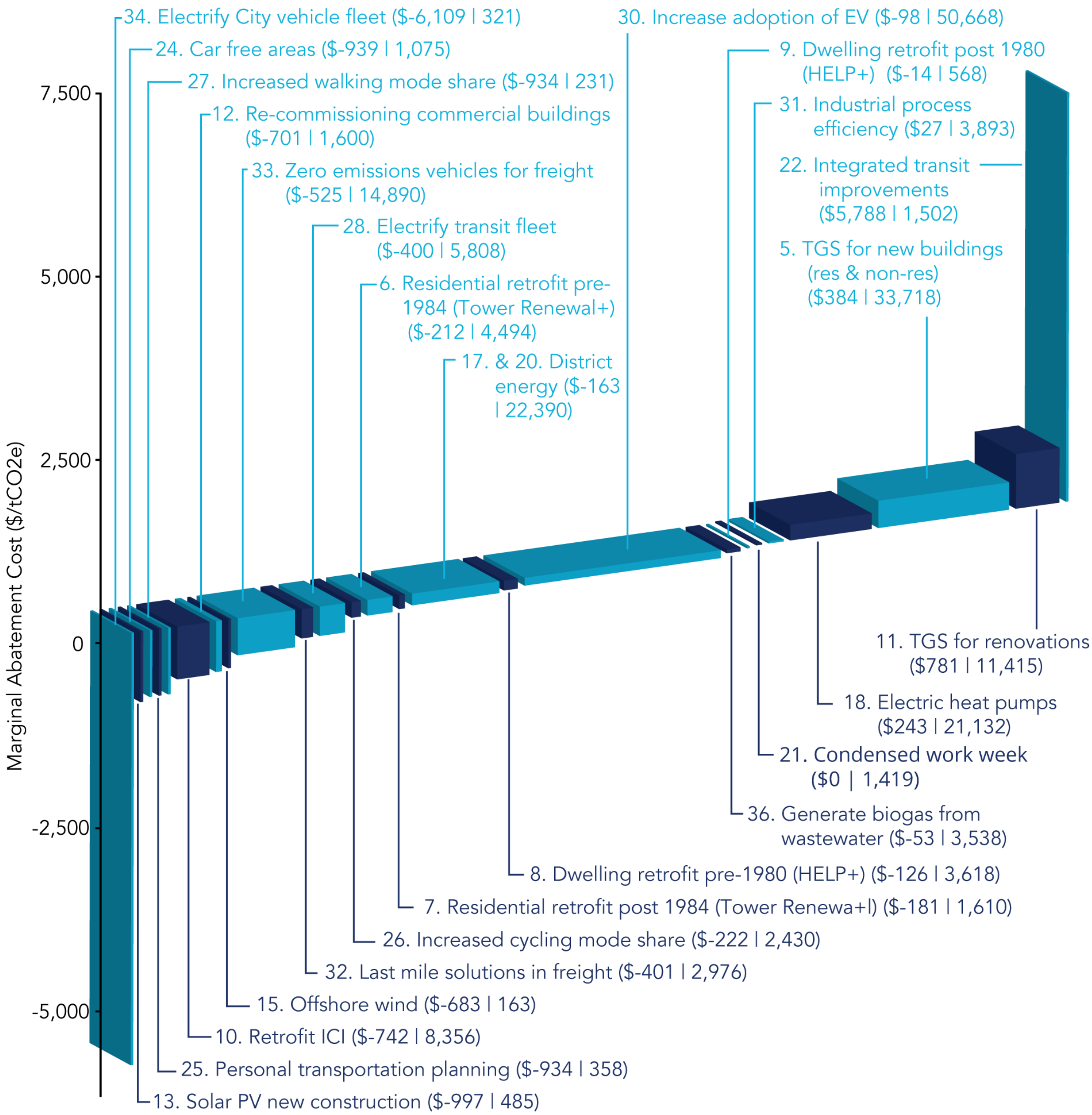

Figure 53. Marginal Abatement Curve

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.

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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.

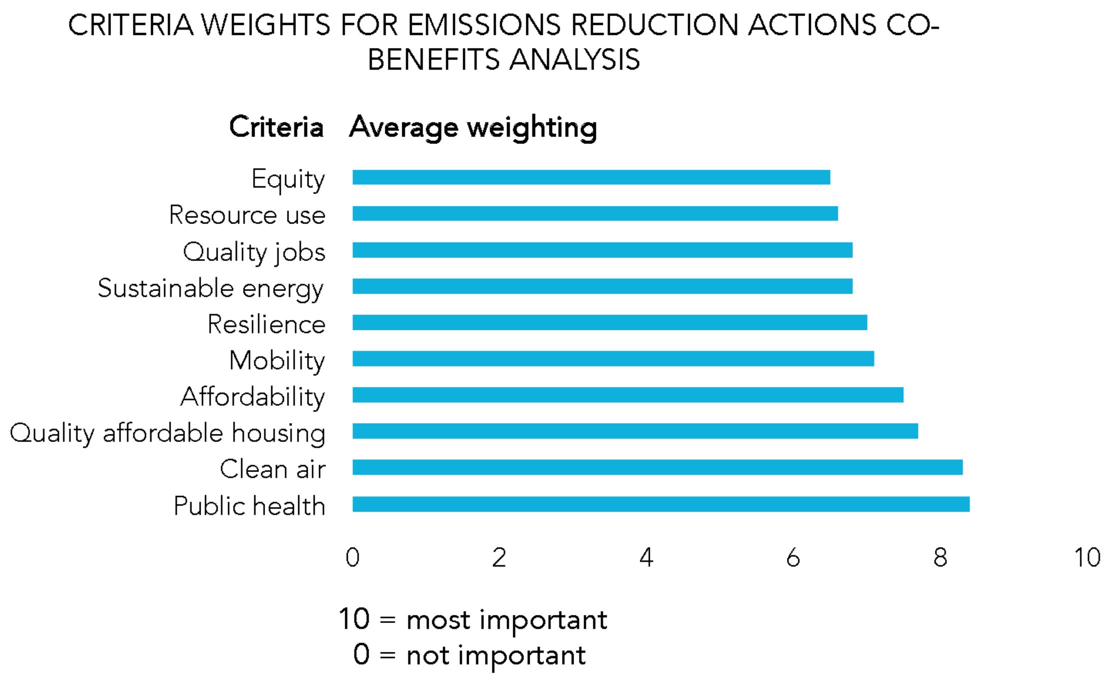

Figure 54. Criteria by weight

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.

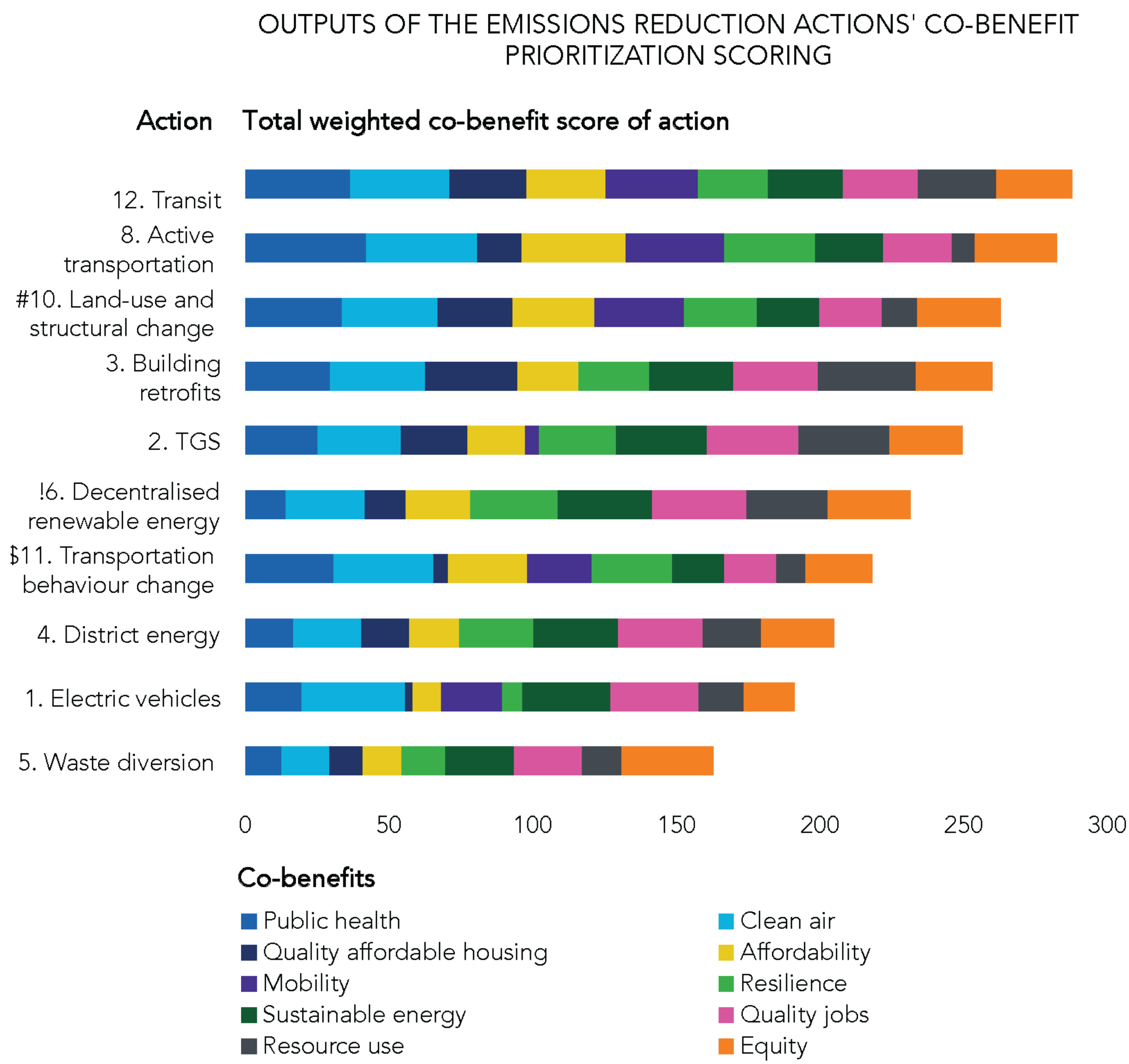

Figure 55. Results of the multi-criteria analysis

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

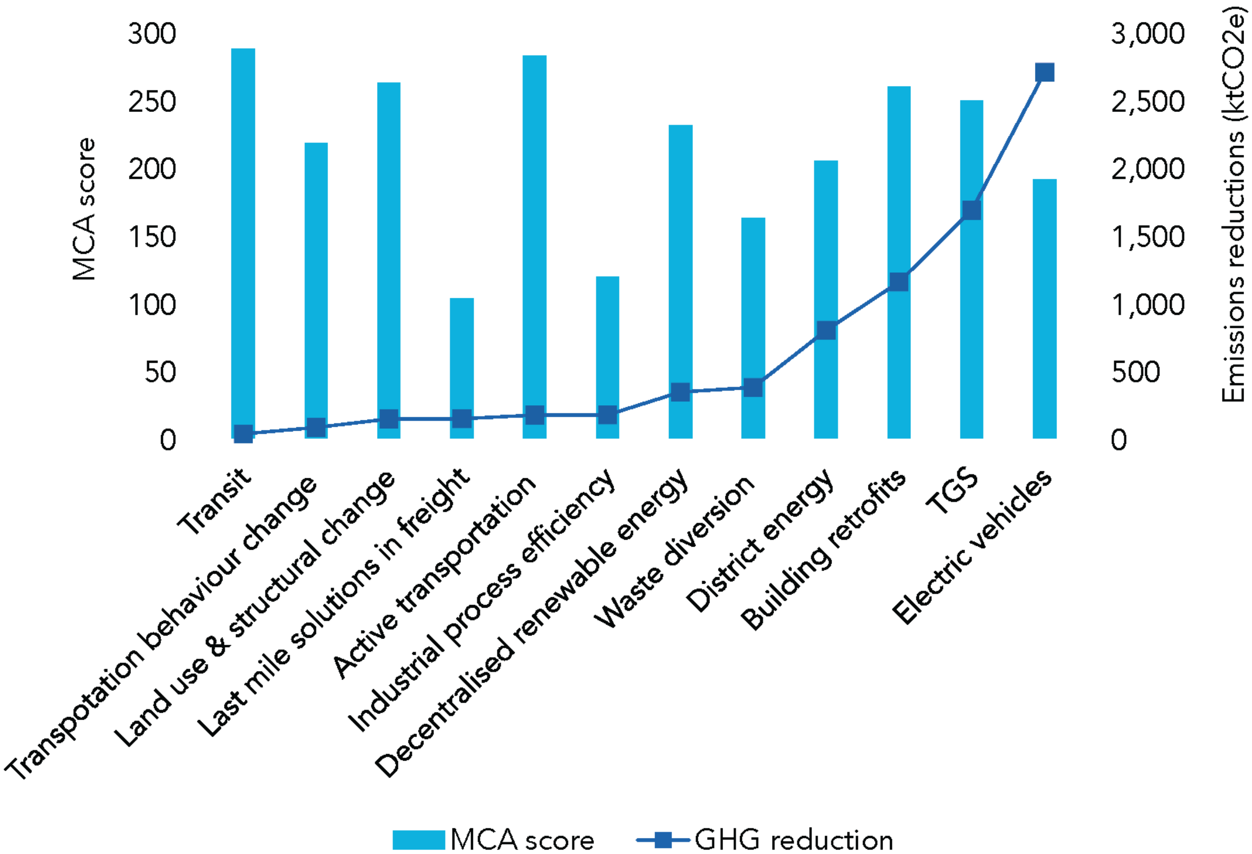

Figure 56. MCA score and GHG emissions reductions

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 • Installation of solar PV systems	• Retrofits in buildings
	High: greater inertia and irreversibility risk	• Electrification of vehicles • District energy systems • Building code improvements	• Land-use planning • 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.

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%)

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%). 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%)