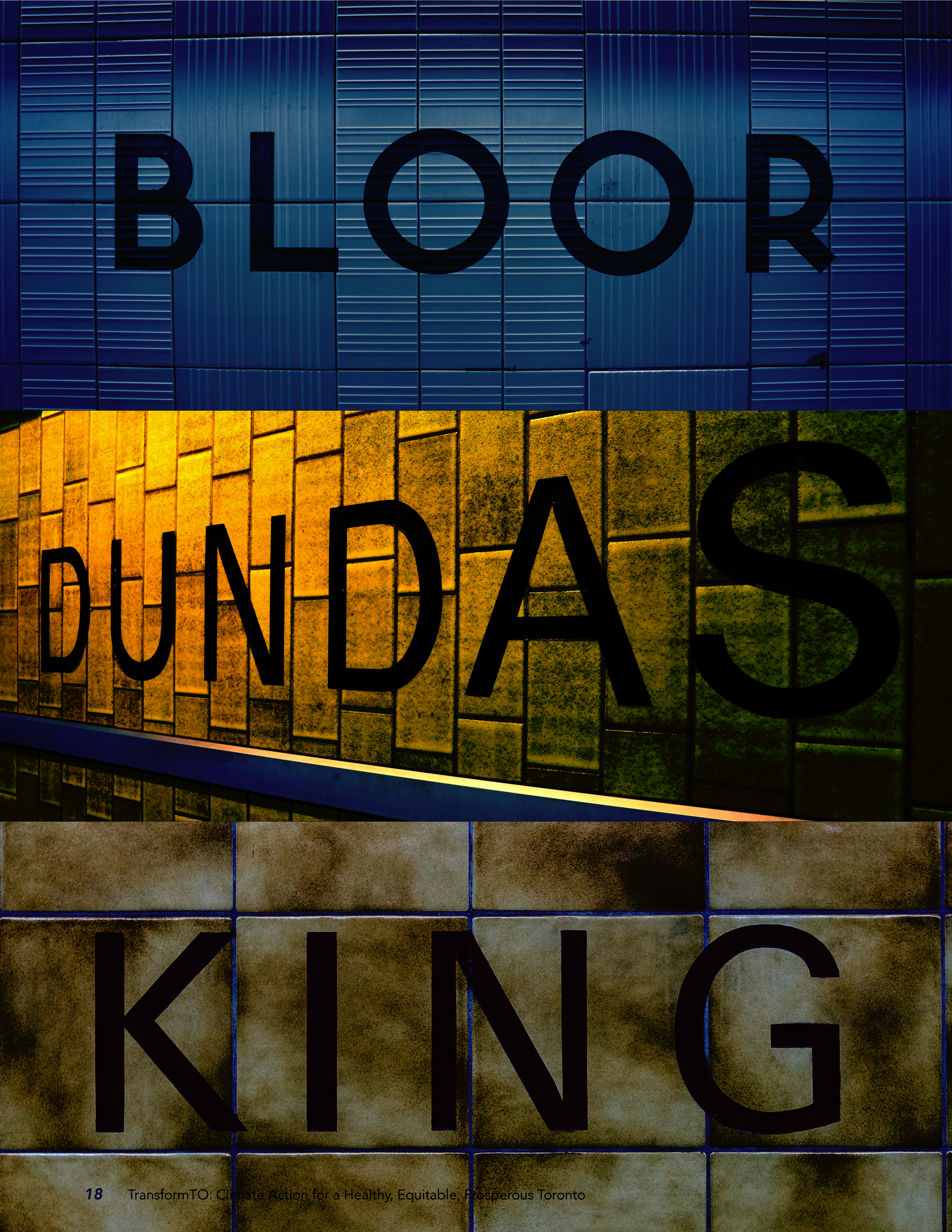
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2. Project Overview

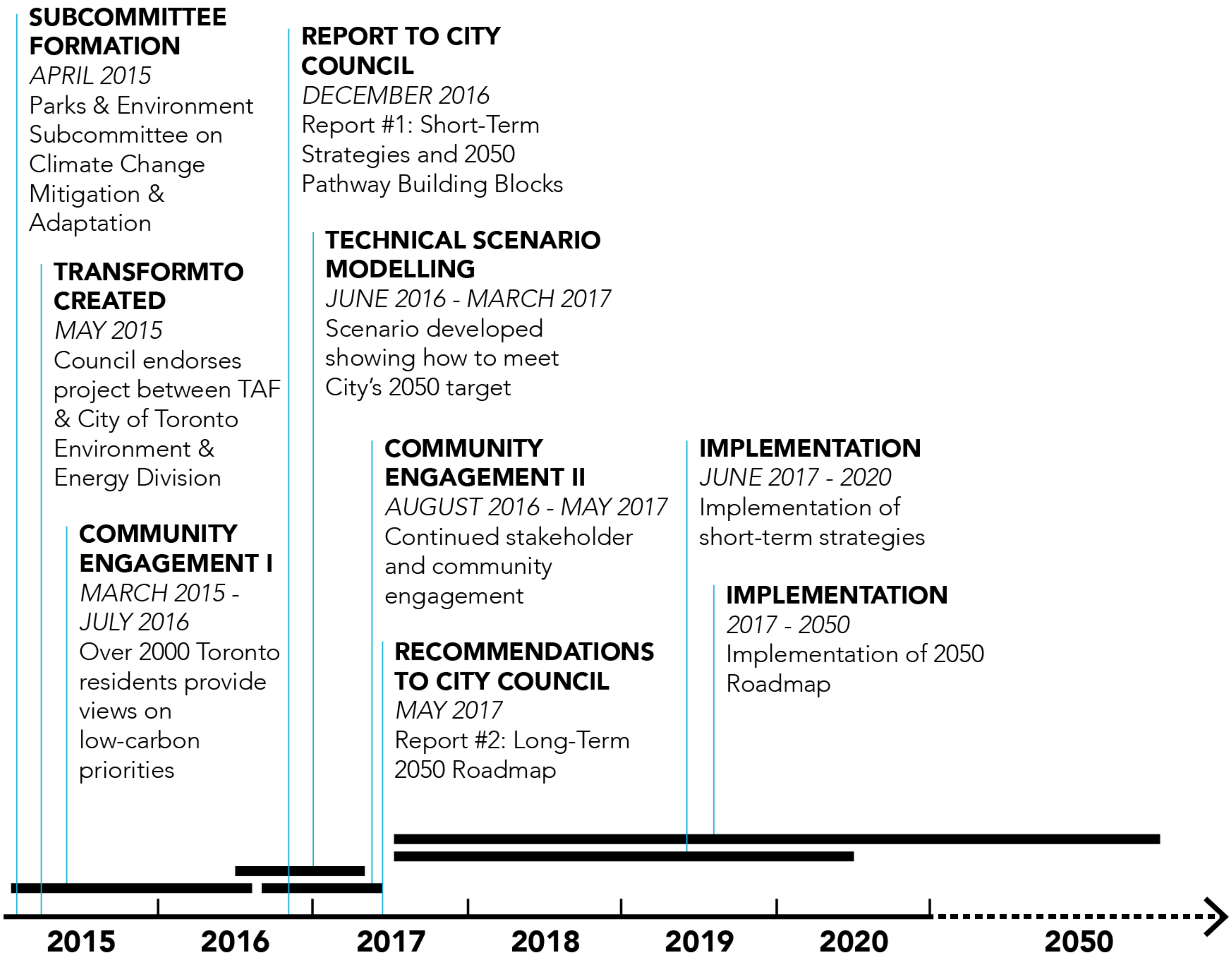

Figure 1. TransformTO timeline

TransformTO included three key components:

1. A community consultation process coordinated by the City;
2. Stakeholder engagement including the Staff Project Steering Team and the Modelling Advisory Group, both of which informed the technical analysis; and
3. Technical modelling and community benefit research led by SSG working with whatIf? Technologies.

Community consultation

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

Stakeholder engagement

Two groups were formed to support the project, including:

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

Technical modelling & community benefit research

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

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

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

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

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

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

18 See Section 6.5 for further details.


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3. Method

3.1 Analysing current conditions

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

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

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

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

A list of key city documents that were reviewed as part of this analysis are described in Appendix 1.

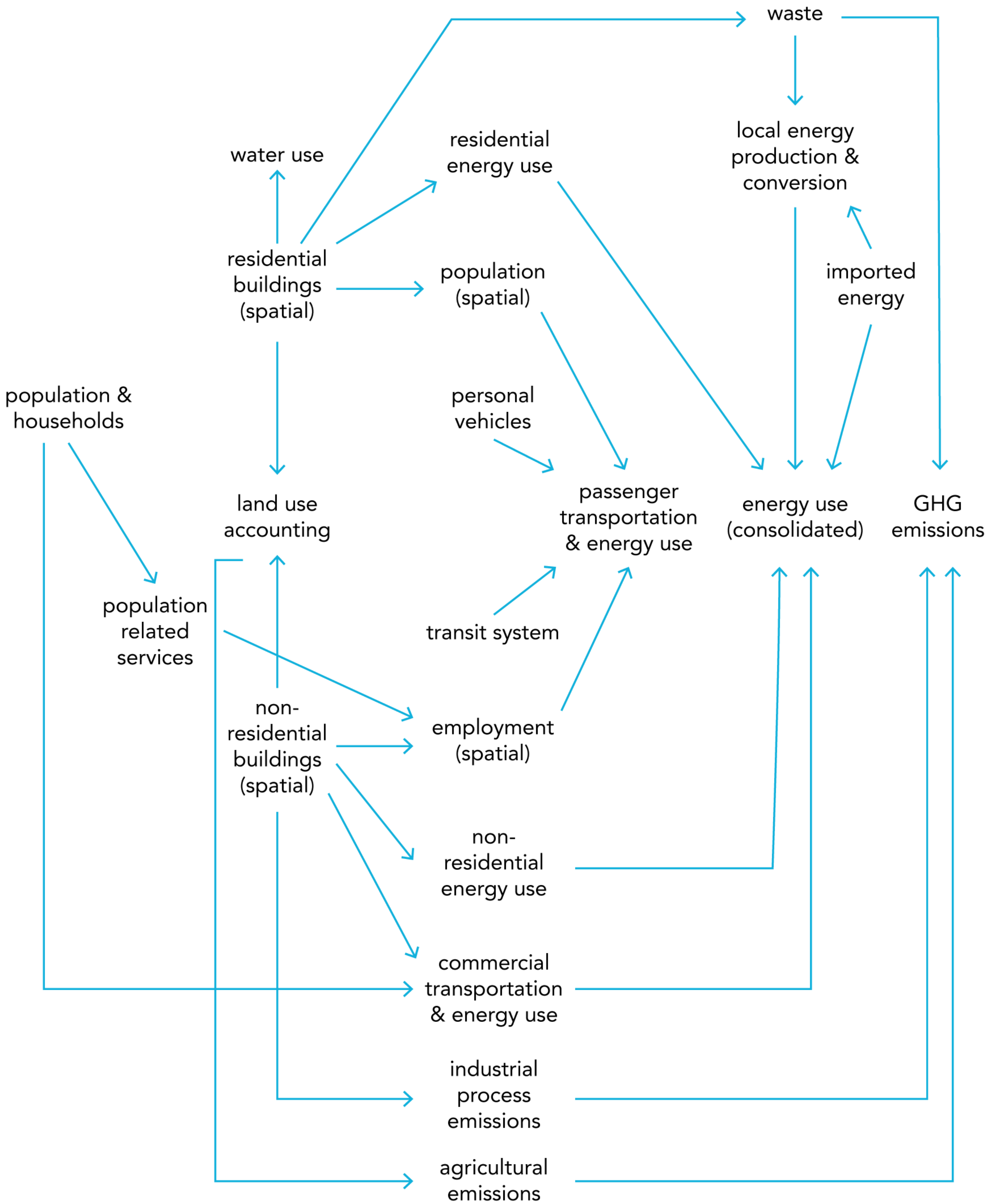

Figure 2. A systems diagram of drivers of urban emissions

3.2 Modelling

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

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

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

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

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

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

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

21 Annual net carbon sequestration of the City's urban forest accounts for 36,500 t CO_2e, less than 0.2% of baseline emissions (*Every Tree Counts, City of Toronto, 2013*).

3.2.1 2011 - the base year

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

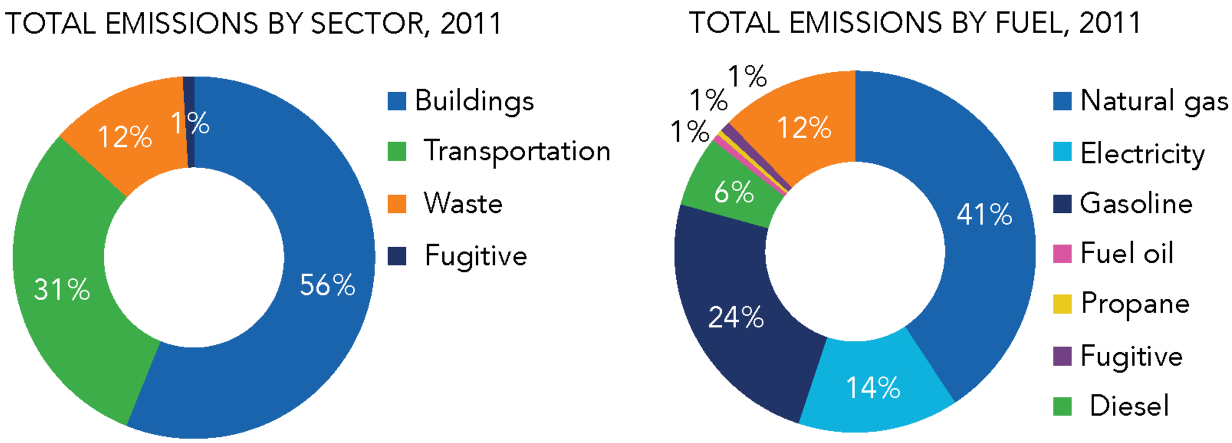

Figure 3. Two views on GHG emissions in 2011.

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

3.3 What does the future hold?

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

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

- A decision tool - "future proofing" a portfolio of activities and proposed actions;
- A prioritization tool - determining where and how to allocate finite resources;
- A testing tool - using multiple "settings" to strengthen an existing strategy, innovation initiative or priority;
- An oversight tool - adding perspective and insight to other planning processes;
- An integrative tool - applying judgment to complexity for making sense of the world;
- A generative tool - producing innovative ideas, programs, products, and services;
- A timing tool - reacting appropriately (i.e. neither overreacting nor underreacting);
- A scanning tool - monitoring for deeper shifts in the external environment;
- A proactive tool - combating reactive demands; taking affirmative steps to prepare for the future; and
- A conversation tool - talking about difficulties in a safe (hypothetical) way.

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

---

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

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

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

- Plausibility. The scenarios must be believable, reflecting current conditions and future trajectories that are intuitive;
- Relevance. The scenarios must provide additional insights to decision-makers on key strategic issues and decisions at hand;
- Challenging. The scenarios must make one think about conventional wisdom, and give rise to different possibilities and options;
- Divergence. Together, the scenarios should "stretch" the thinking about the future environment, so that the decisions take account of a wider range of issues;
- Balanced. The scenarios should strike a balance between challenges and opportunities, risks, and upside potential.

3.4 Conceptualizing scenarios

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

3.4.1 The BAP: A representation of status quo

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

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

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

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

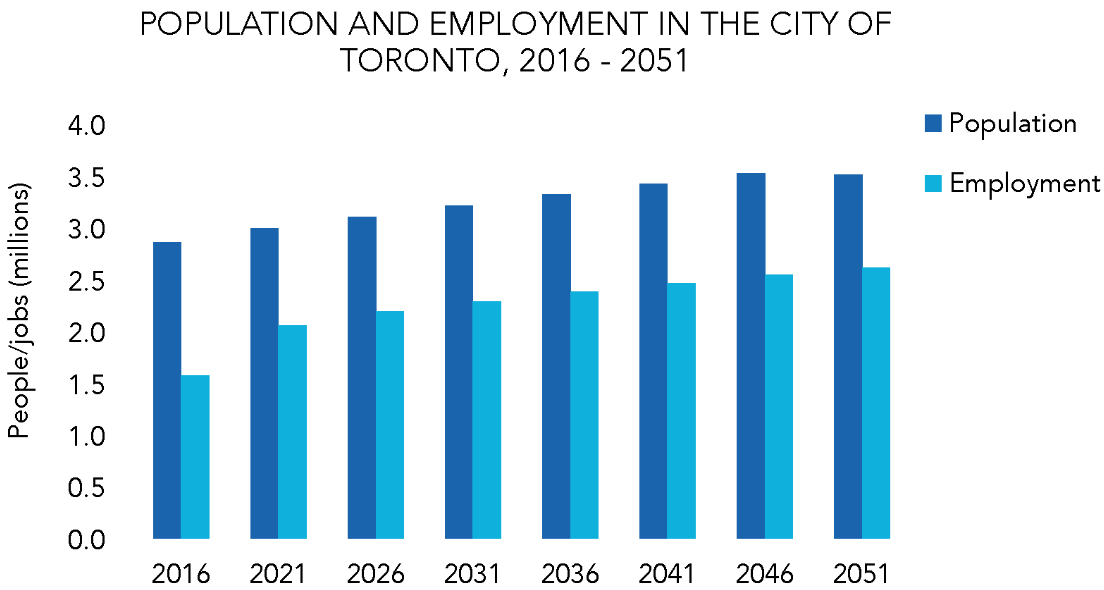

Figure 4. Population and employment projections, 2016-2051.

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

25 This estimate accounts for census undercount and external students.

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

CURRENT, FUNDED, AND PROPOSED TRANSIT IN THE CITY OF TORONTO, AND MODELLED POPULATION AND EMPLOYMENT DENSITIES BY ZONE IN 2051.

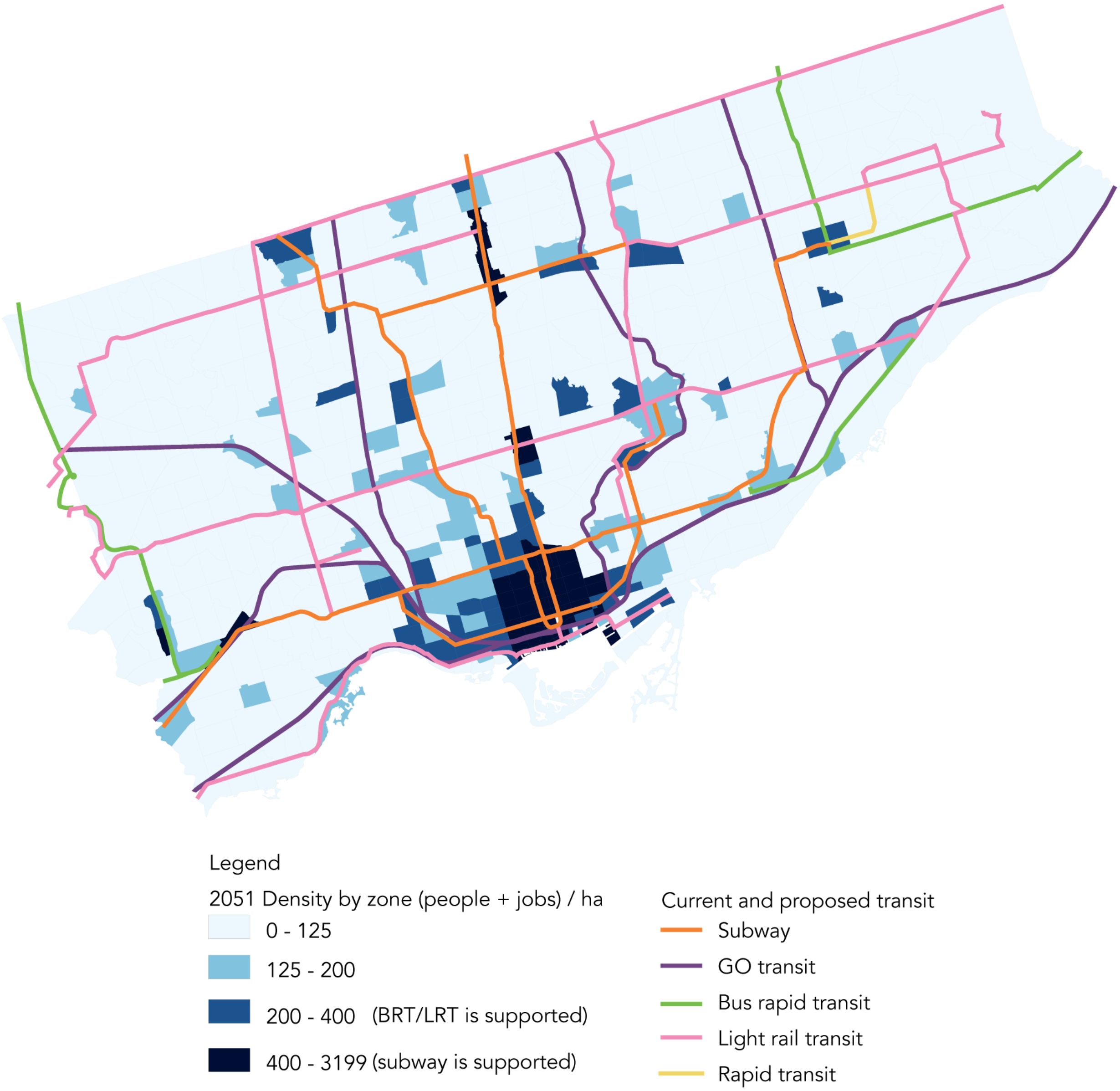

Figure 5. Relationship between density (people and jobs) and the projected transit system.

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

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

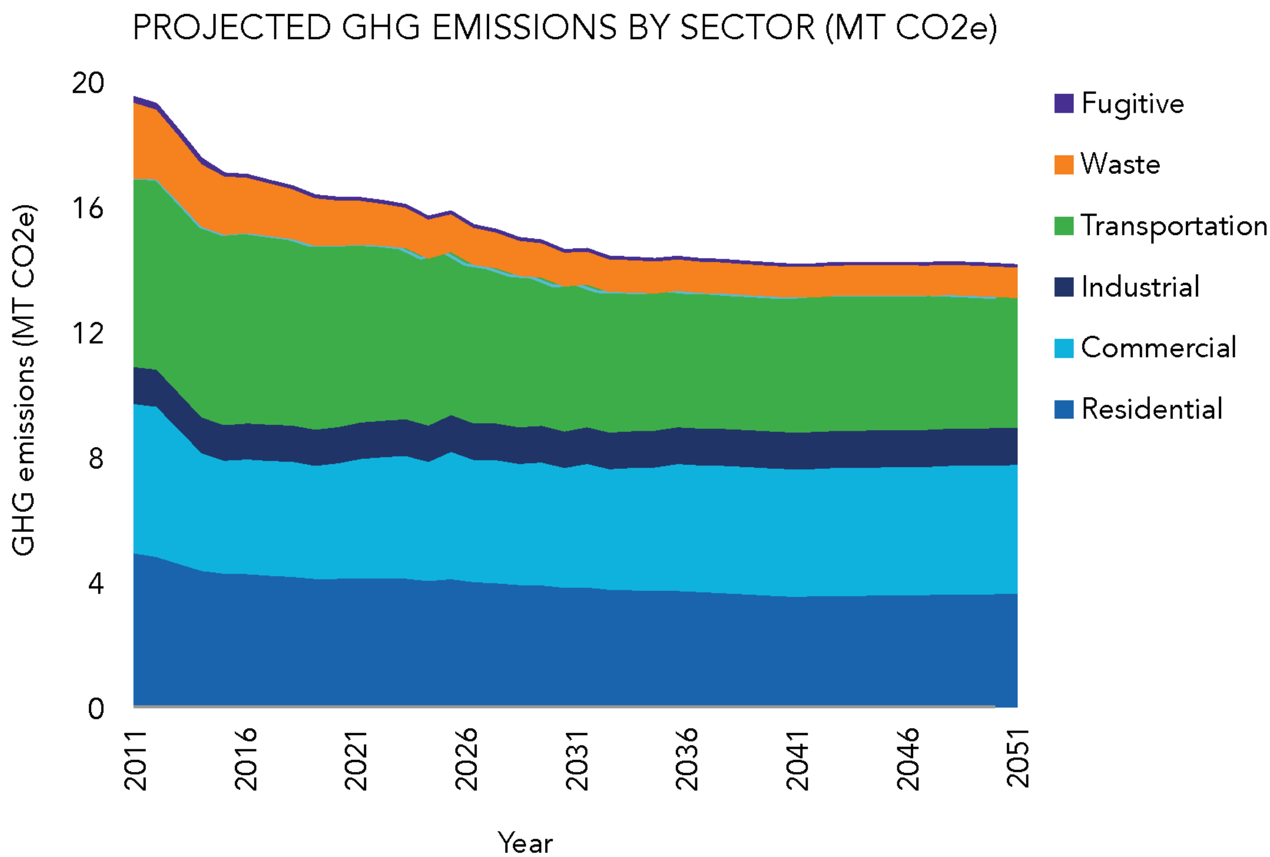

Figure 6. BAP - Projected GHG emissions by sector (MT CO2e).

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

- Decline of grid electricity emissions factor, particularly over the period of 2012 to 2016 as coal generation was phased out in the electricity grid;
- Improving vehicle fuel efficiency standards;
- Decrease in heating degree days (due to a warming climate), partially offset by an increase in cooling degree days (Figure 7);
- Increase in energy retrofits of existing buildings;
- Increased efficiency in new construction;
- Increasing numbers of electric vehicles in overall stock of vehicles; and
- Increasing diversion rates in solid waste.

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

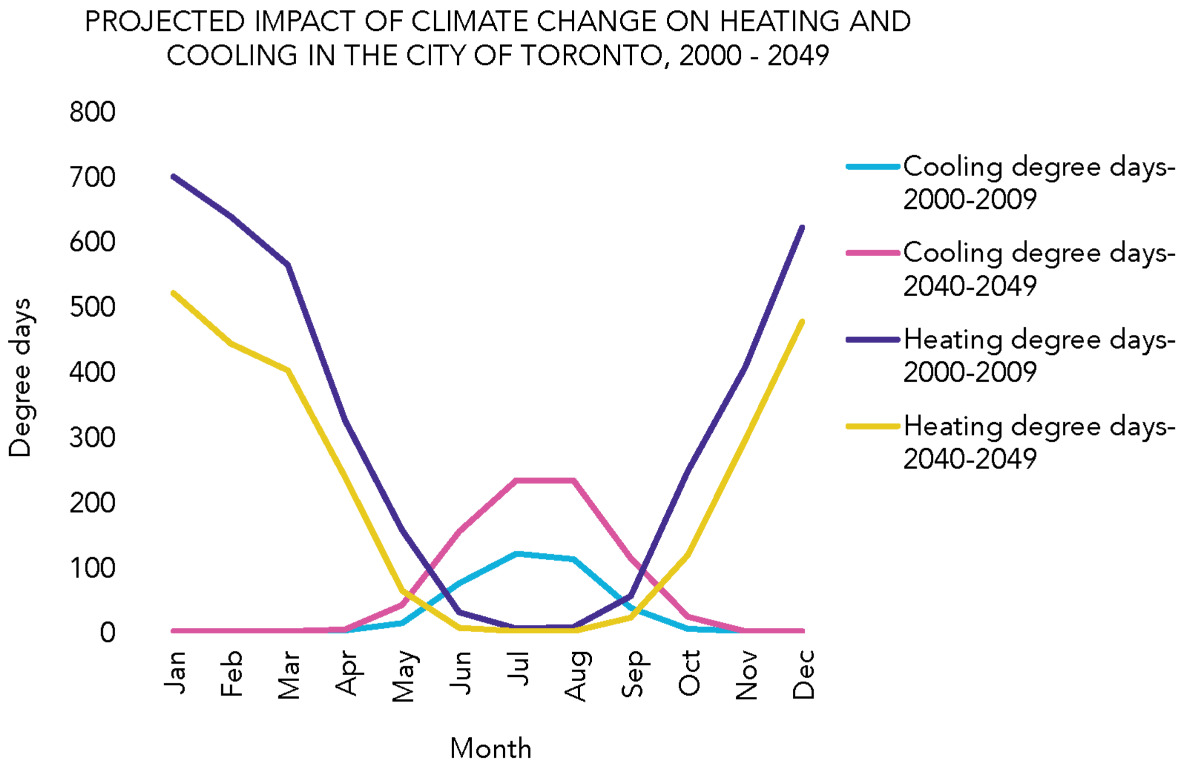

Figure 7. Heating and cooling degree days in 2000-2009 and 2040-2049[29]

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

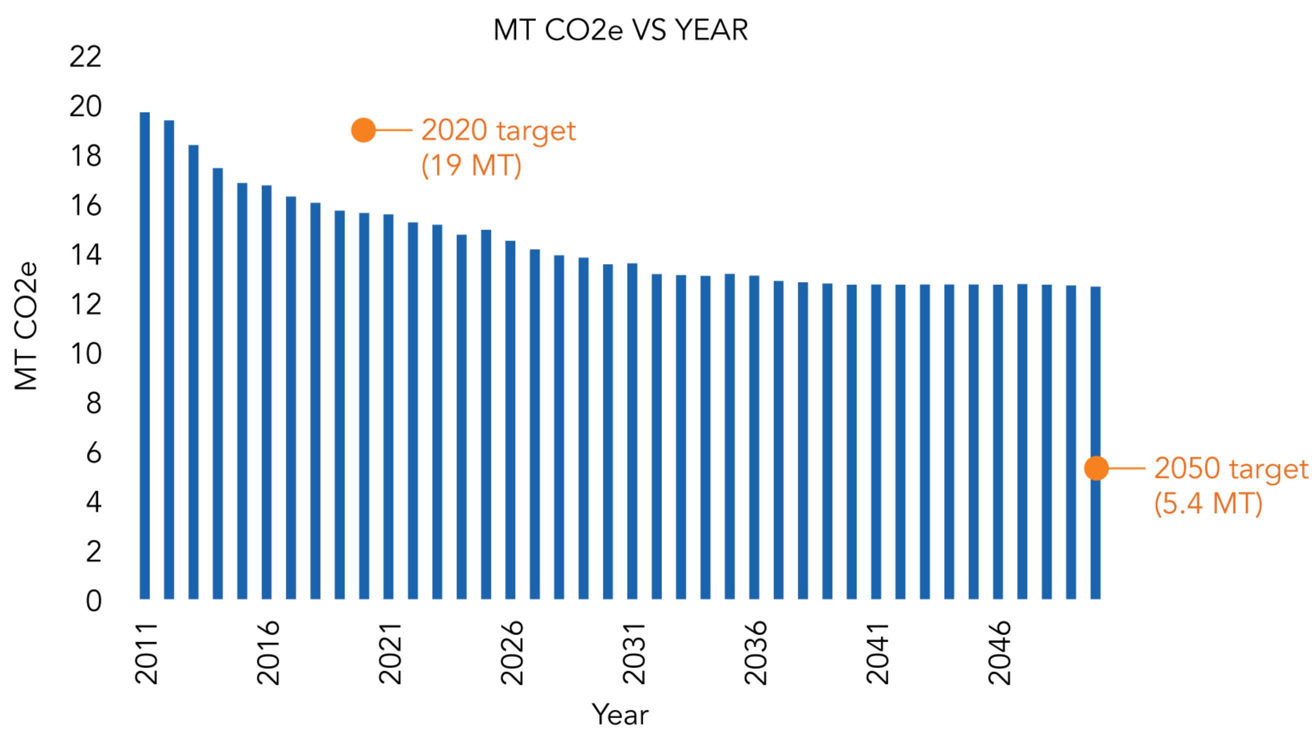

Figure 8. Annual GHG emissions for the BAP, including the 2011 baseline.

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

3.4.2 The Low Carbon Scenario

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 3. In the numbers[34,35]

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

34 Internal trips refer to trips within the city boundary.

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

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4. Five urban systems

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

4.1 Land-use

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

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

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

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

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

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

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

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

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

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

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

Observations

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

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

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

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

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

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

4.2 Buildings

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

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

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

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

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

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

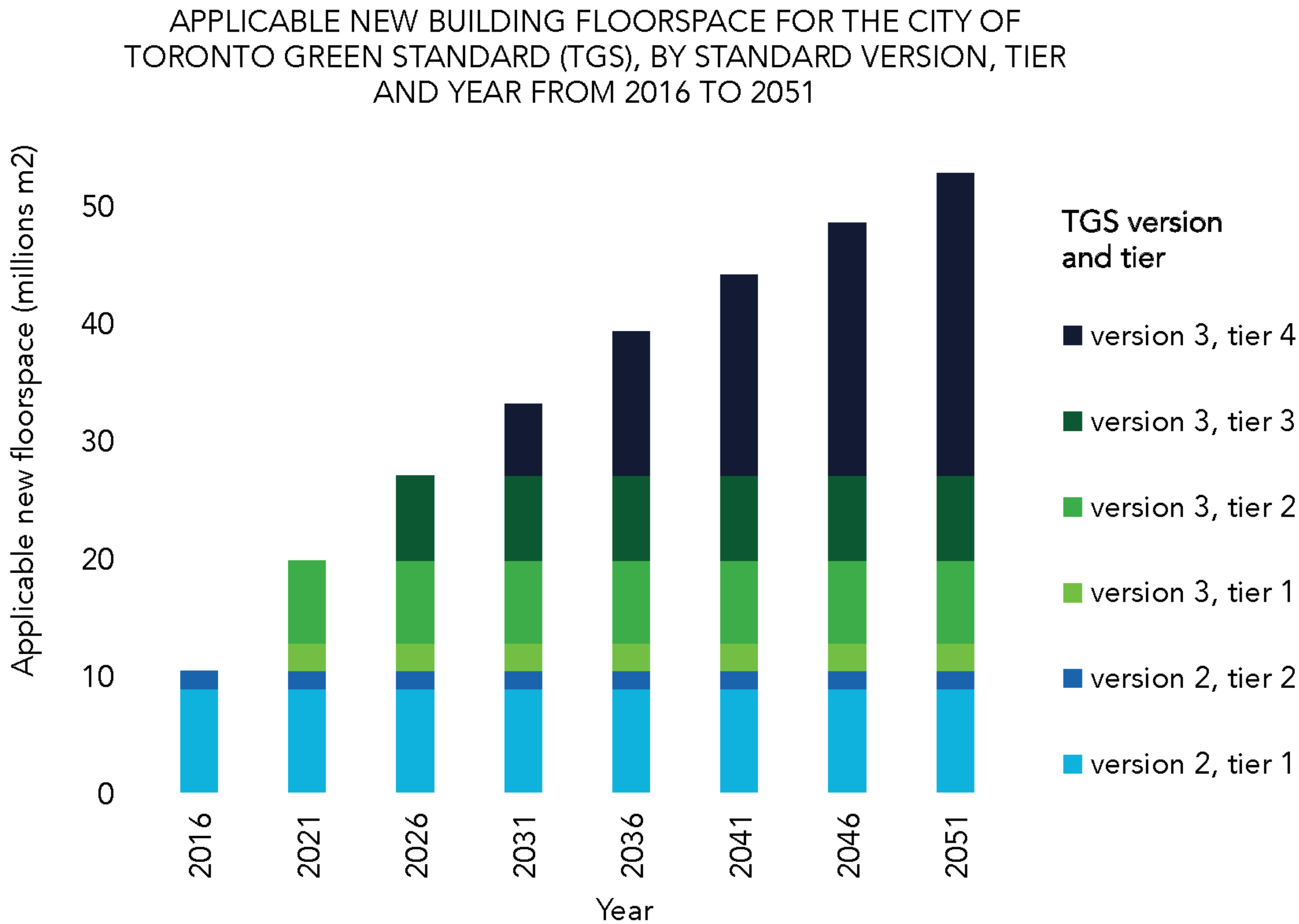


Figure 9. The application of TGS standards to new buildings post 2016

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

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

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

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

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

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

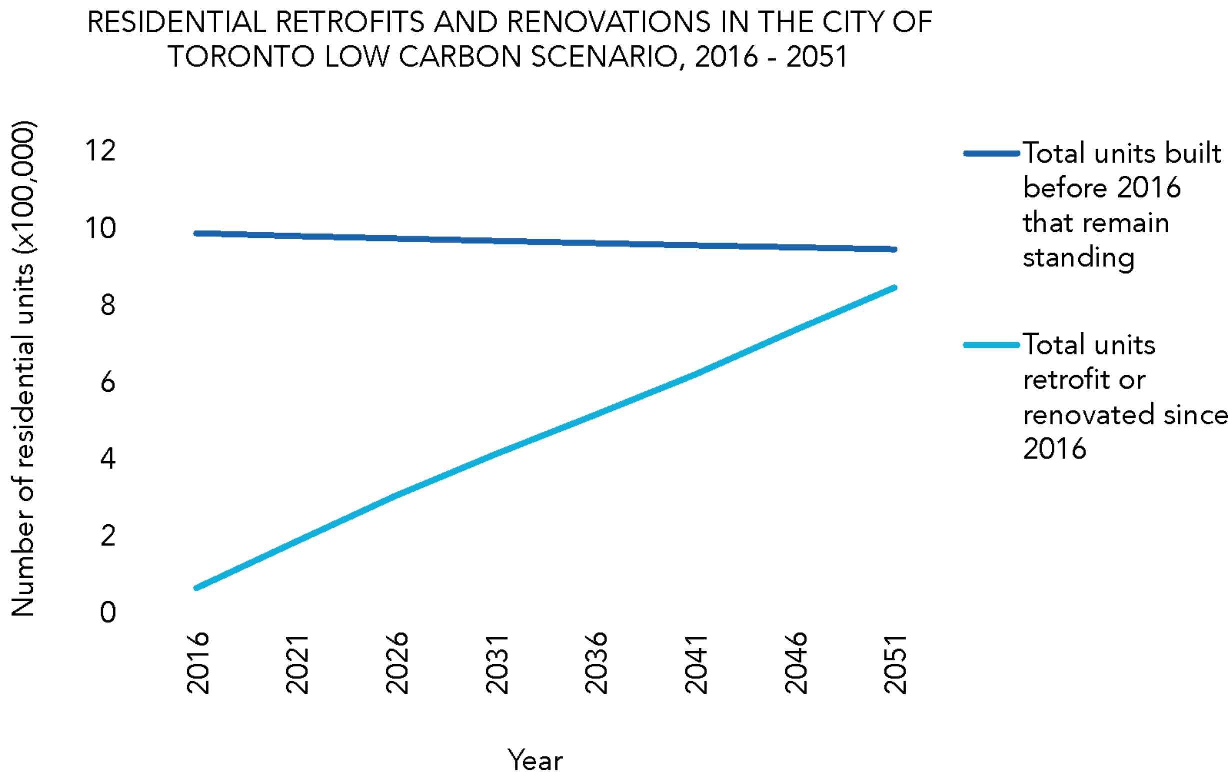


Figure 10. Number of dwelling units in the city either retrofit or renovated

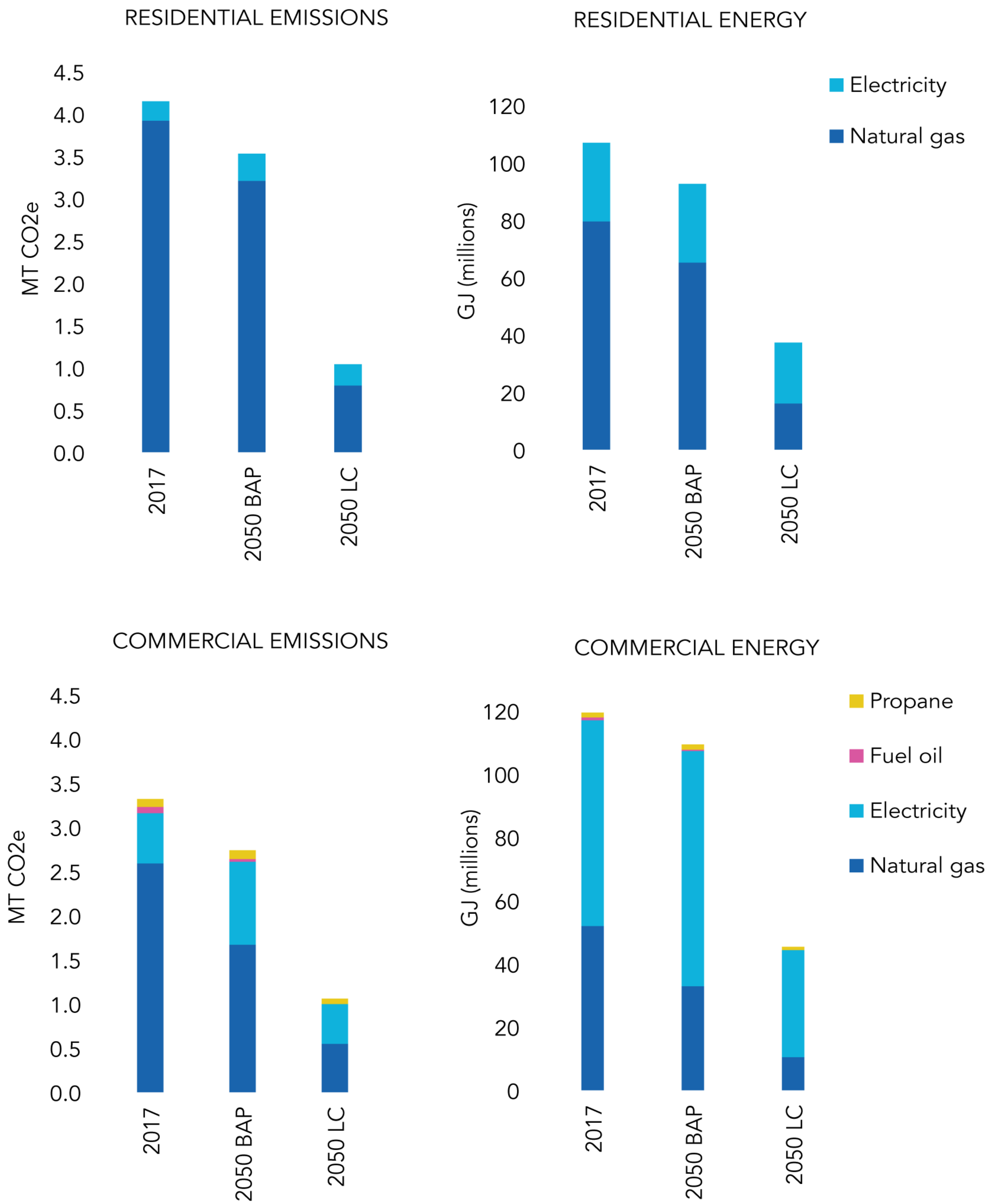


Figure 11. Residential and commercial energy and emissions by fuel.

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

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

Observations

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

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

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

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

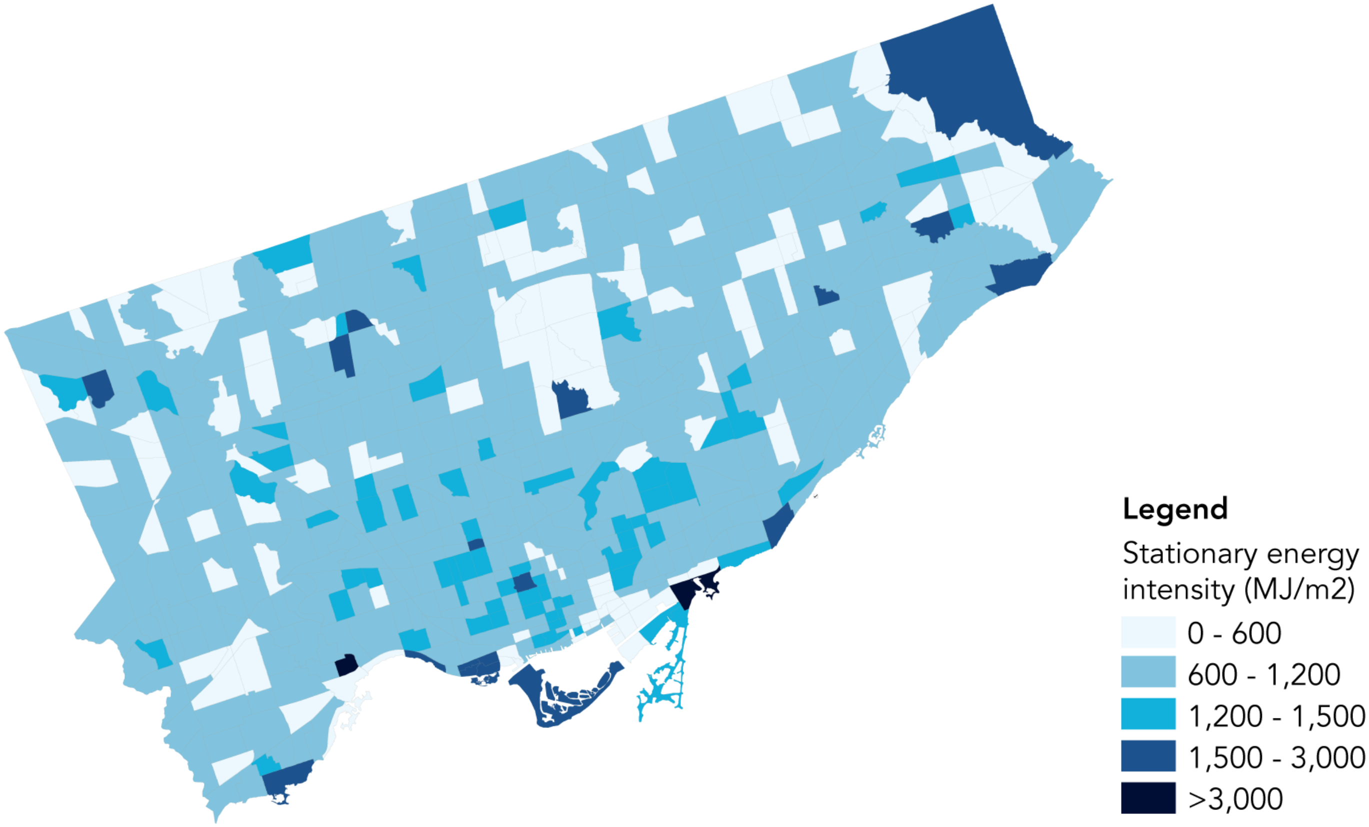


Figure 12. Building energy intensity (MJ/m2 by zone), BAP 2050.

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

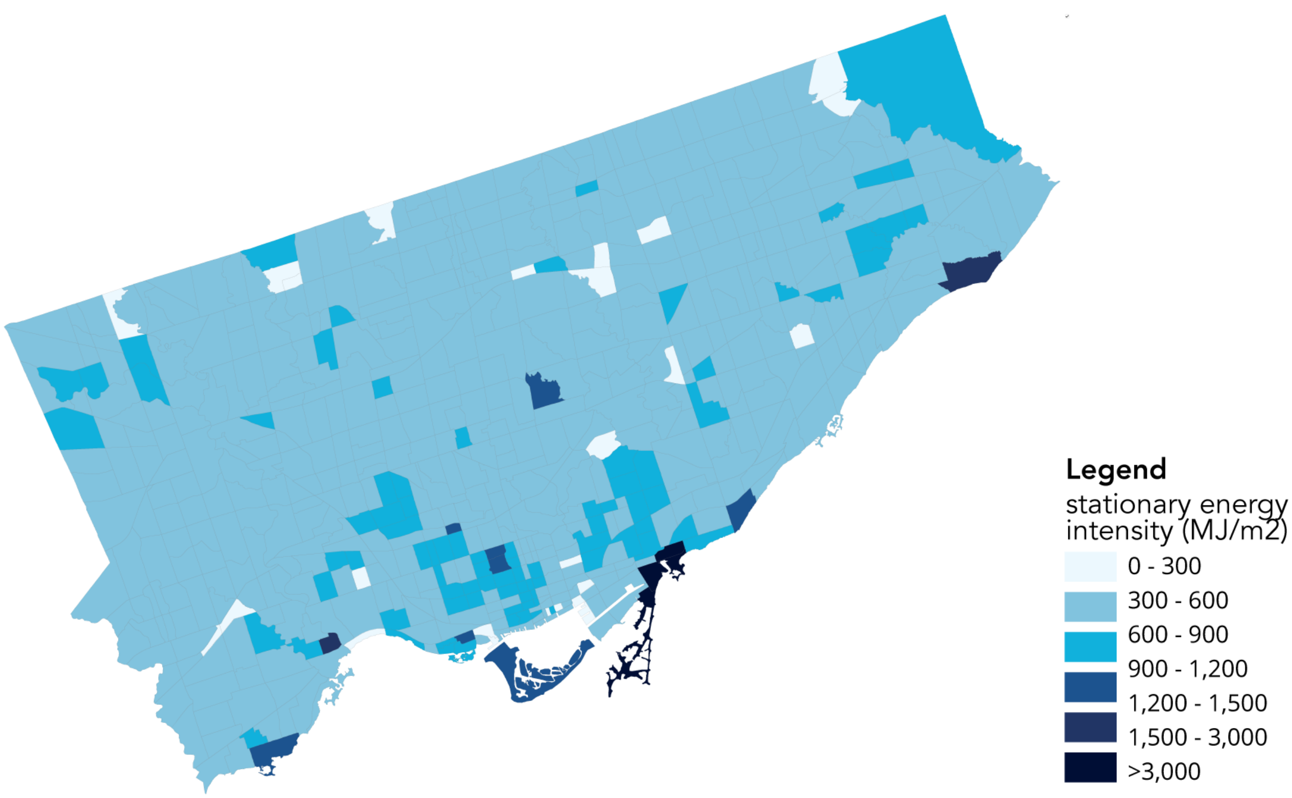


Figure 13. Building energy intensity (MJ/m2), Low Carbon 2050.

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

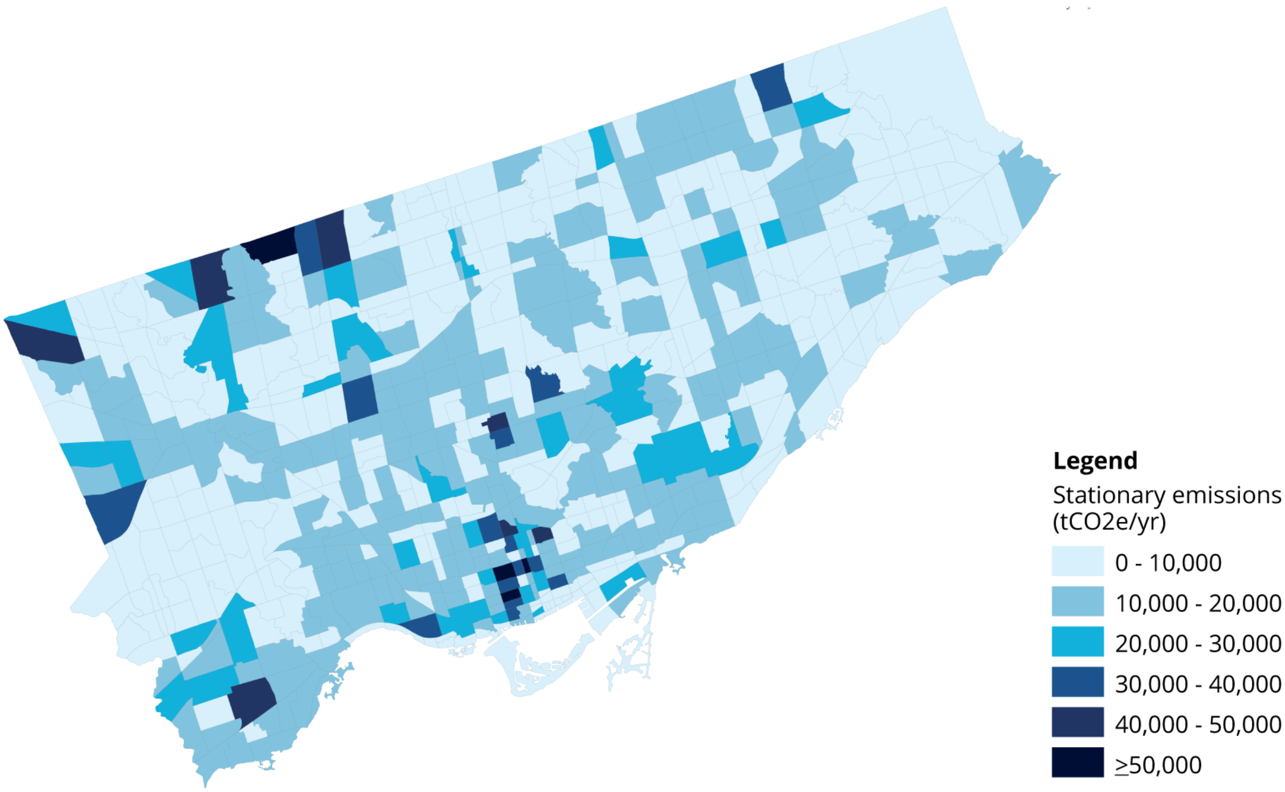


Figure 14. Building emissions (tCO2e/yr), BAP 2050.

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

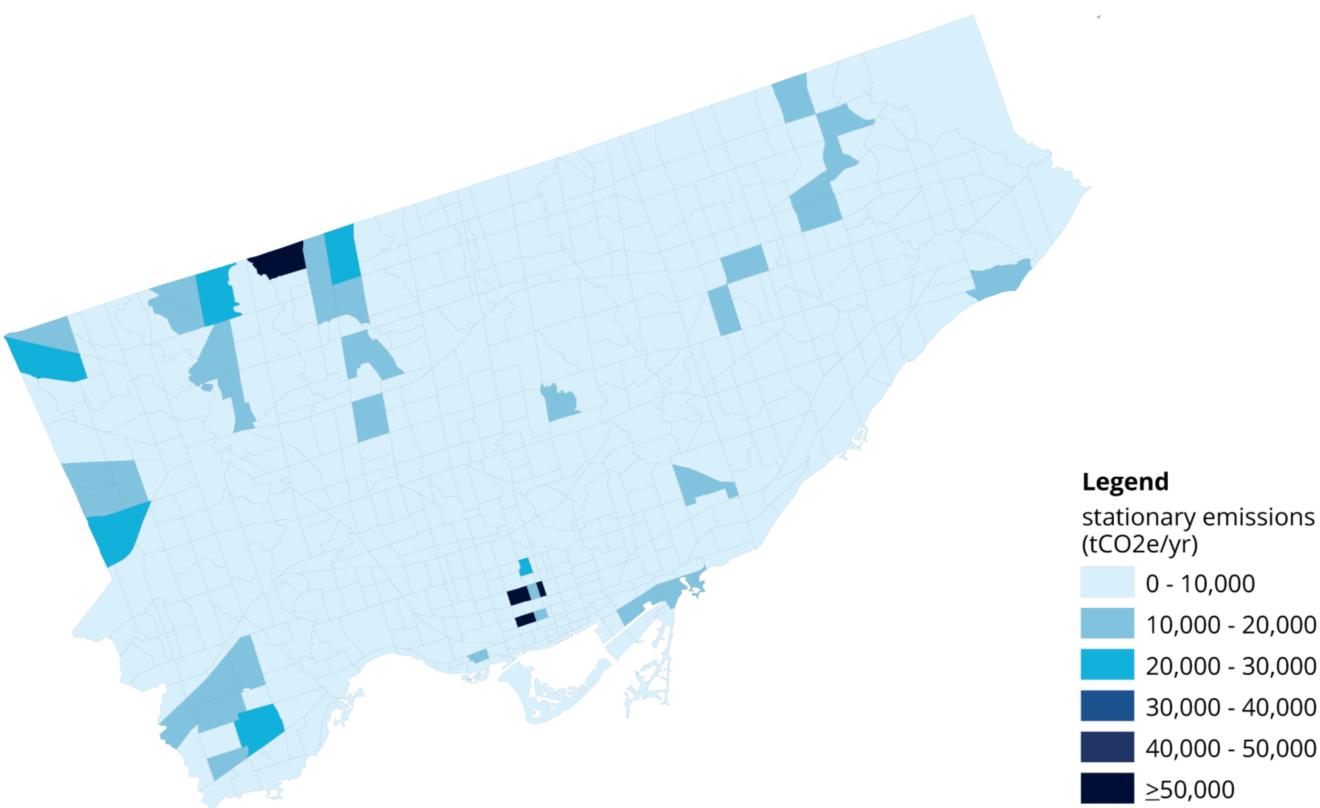


Figure 15. Building emissions (tCO2e/yr), Low Carbon 2050.

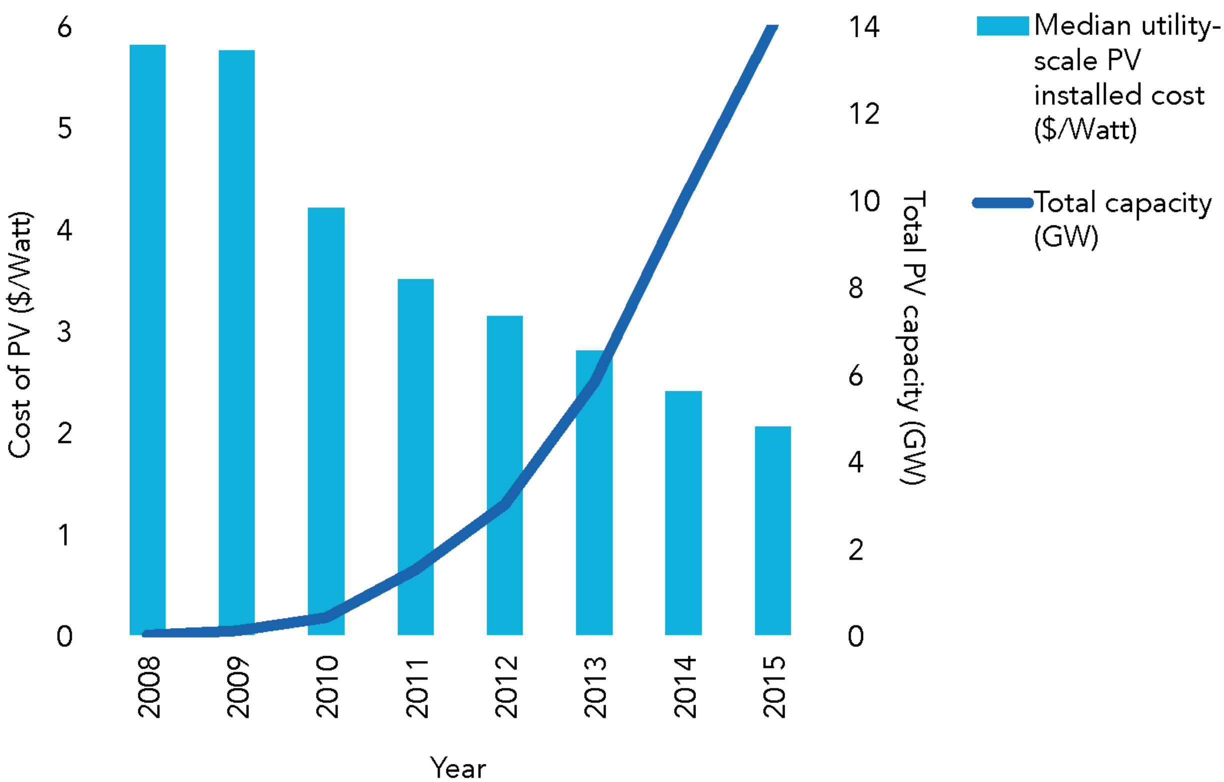
There are two key strategies for buildings; firstly, retrofit the existing or pre-2016 building stock and secondly increase the efficiency of the post-2016 buildings stock to near net zero GHG emissions. Both of these strategies build on existing efforts within the City, which need to be scaled up. The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

4.3 Energy system

LCS Modelling Assumption: Buildings are renewable energy generators.

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

SOLAR ENERGY COSTS AND DEPLOYMENT IN THE UNITED STATES



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

Figure 16. Costs of solar PV

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

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

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

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

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

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

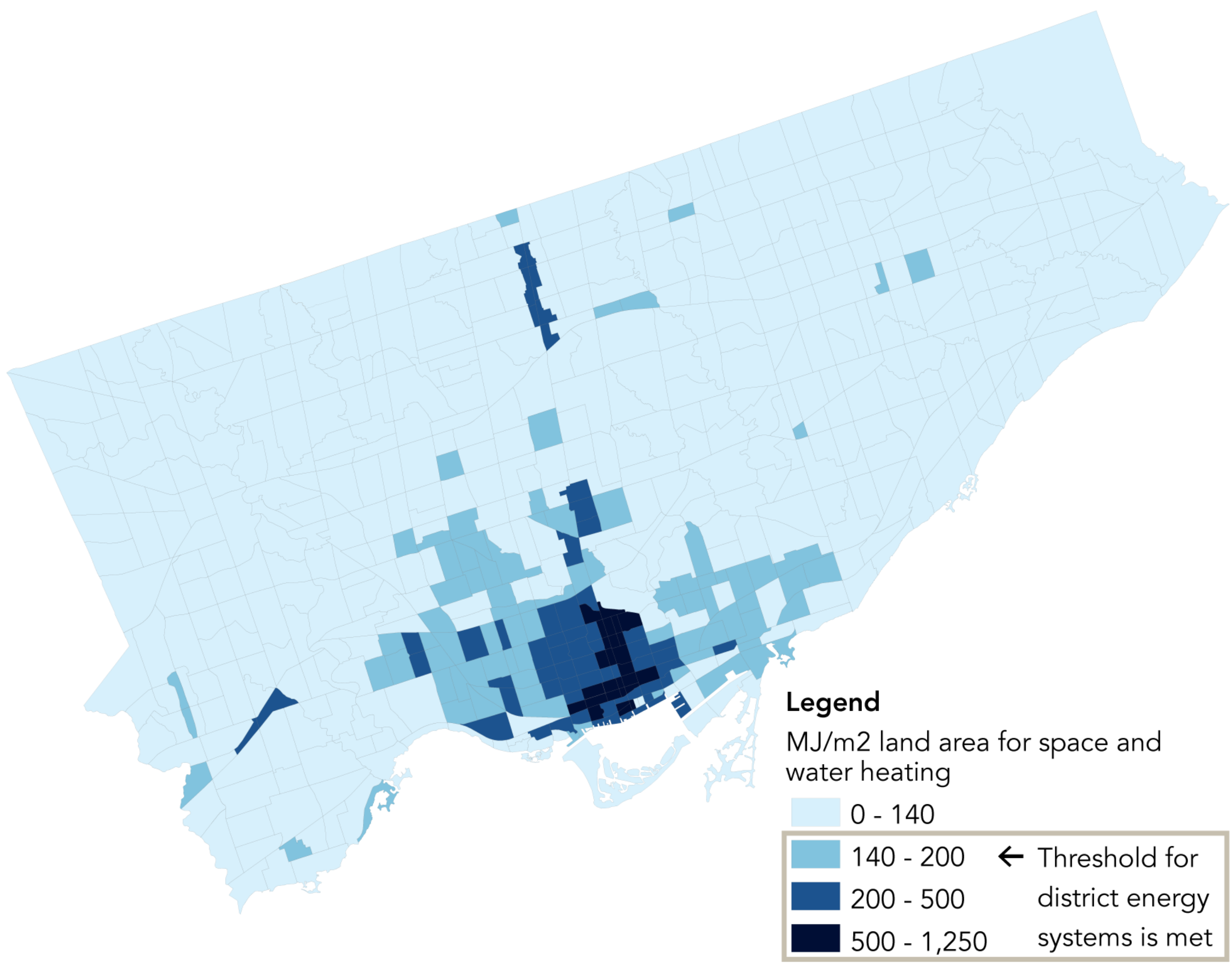


Figure 17. Zones identified in the modelling that meet or exceed the 140 MJ/ m^2 threshold for district energy in the 2050 LCS.

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

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

- biogas (renewable natural gas)- 41%
- geothermal- 21%
- industrial waste heat- 17%
- deepwater cooling-13%; and
- facade combined heat and power solar- 8%.

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

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

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

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

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

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

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

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

LCS Modelling Assumption: Industrial efficiencies continue to improve.

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

Observations

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

4.4 Transportation

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

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

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

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

LCS Modelling Assumption: Neighbourhoods become car free.

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

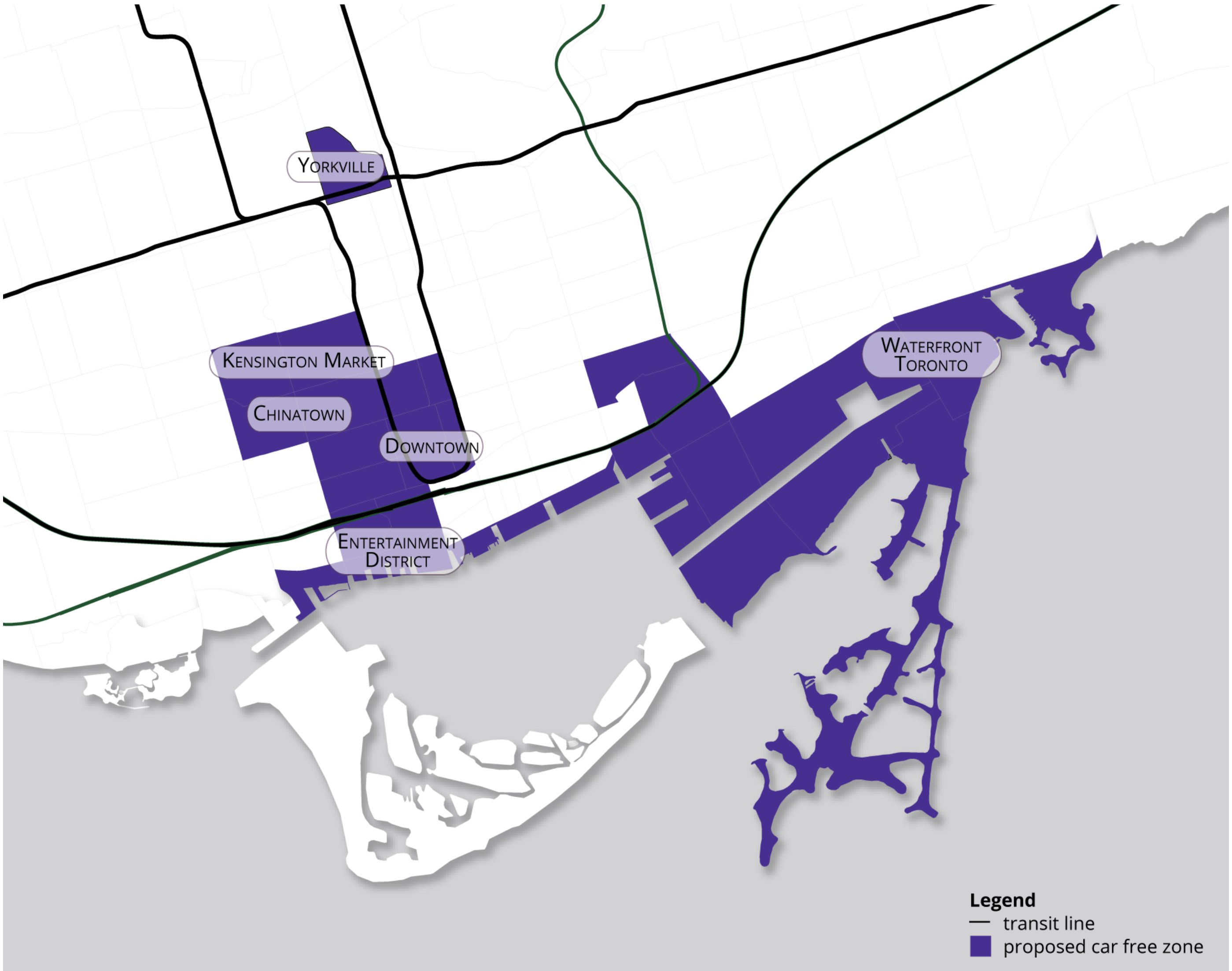


Figure 18. Car free zones.

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

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

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

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

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

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

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

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

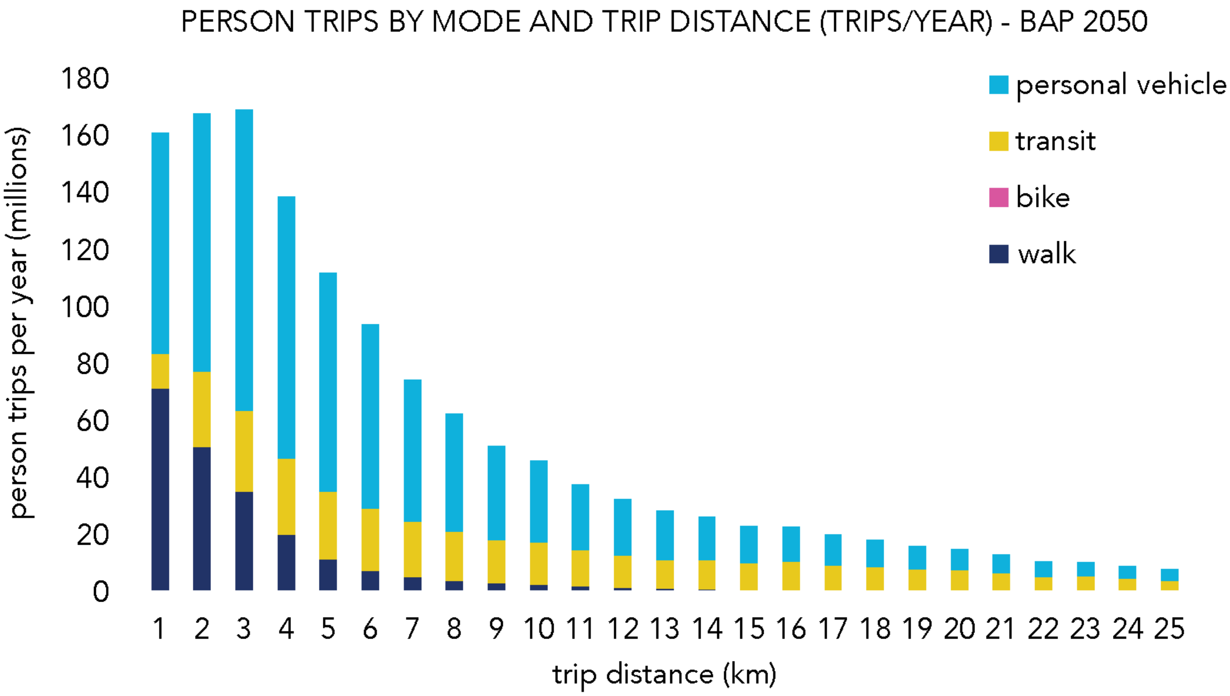


Figure 19. Person trips by mode and distance, BAP 2050.[56]

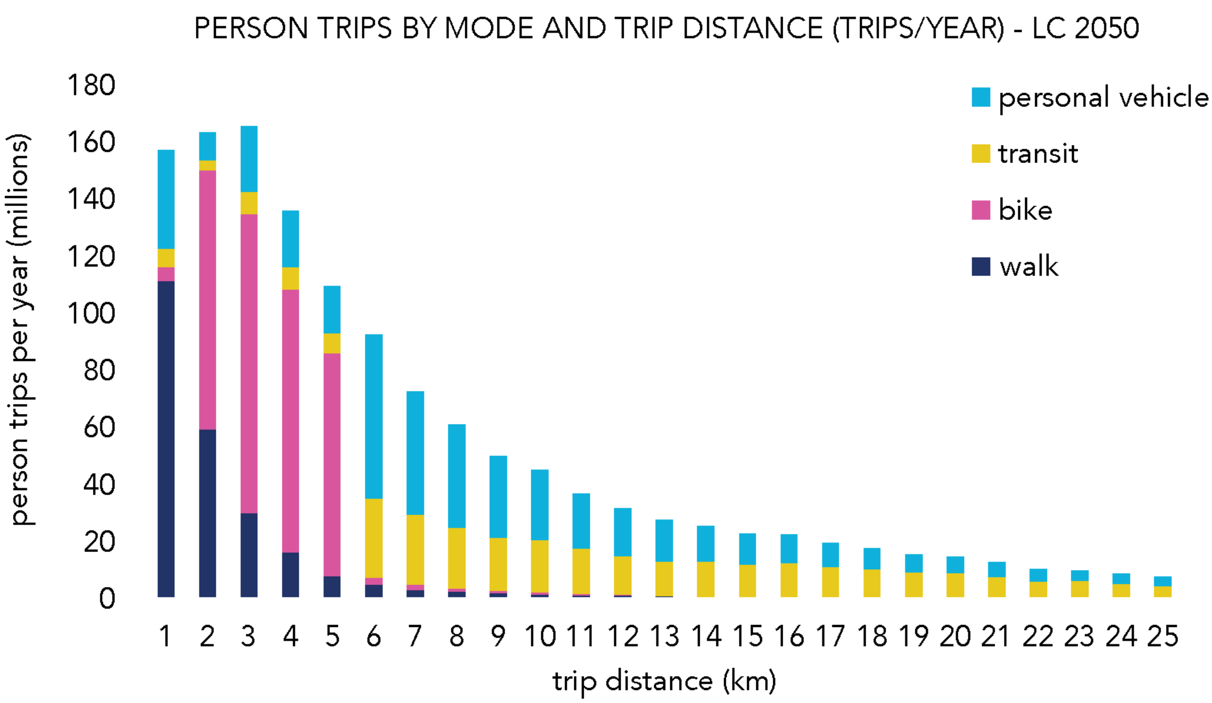


Figure 20. Person trips by mode and distance, Low Carbon 2050.

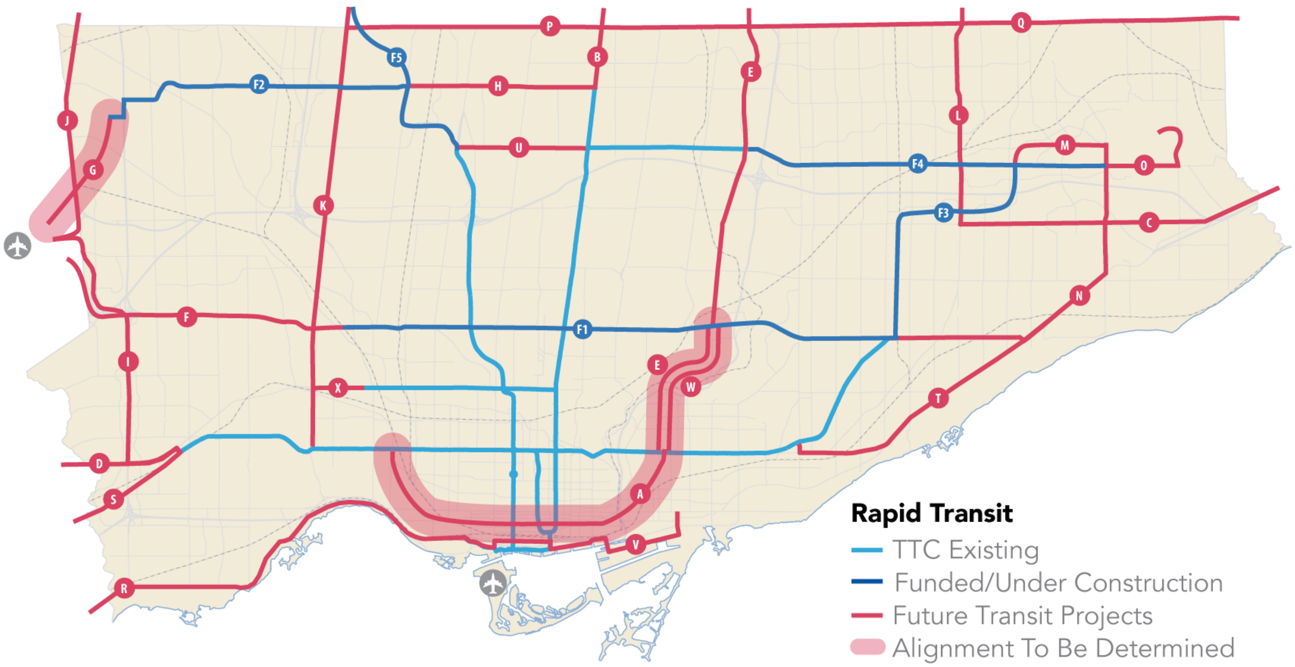
56 Note that the City does not split out walking and cycling trips in its transportation modelling so walking and cycling trips were classified as active transportation.

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

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

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

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



Currently Funded Rapid Transit Projects

- F1 Eglinton Crosstown LRT
- F2 Finch West LRT
- F3 Scarborough RT Replacement & Extension
- F4 Sheppard East LRT
- F5 Toronto-York Spadina Subway Extension (TYSSE)

Unfunded Future Rapid Transit Projects

- A Relief Line (subway)
- B Yonge North Subway Extension
- C Durham-Scarborough BRT
- D Dundas Street BRT
- E Don Mills LRT
- F Eglinton LRT West Extension
- G Finch West LRT West Extension
- H Finch West LRT East Extension
- I Highway 427 Airport BRT South
- J Highway 427 Airport BRT North
- K Jane LRT
- L McCowan Road BRT
- M Scarborough RT/LRT Extension
- N Scarborough Malvern LRT
- O Sheppard East LRT Extension
- P Steeles LRT/BRT West
- Q Steeles LRT/BRT East
- R Waterfront West LRT
- S Bloor-Danforth Subway West Extension
- T Kingston Road BRT
- U Sheppard West Corridor
- V Waterfront East LRT
- W Relief Line East Extension (subway)
- X St. Clair Streetcar/LRT Extension

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

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

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

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

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

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

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

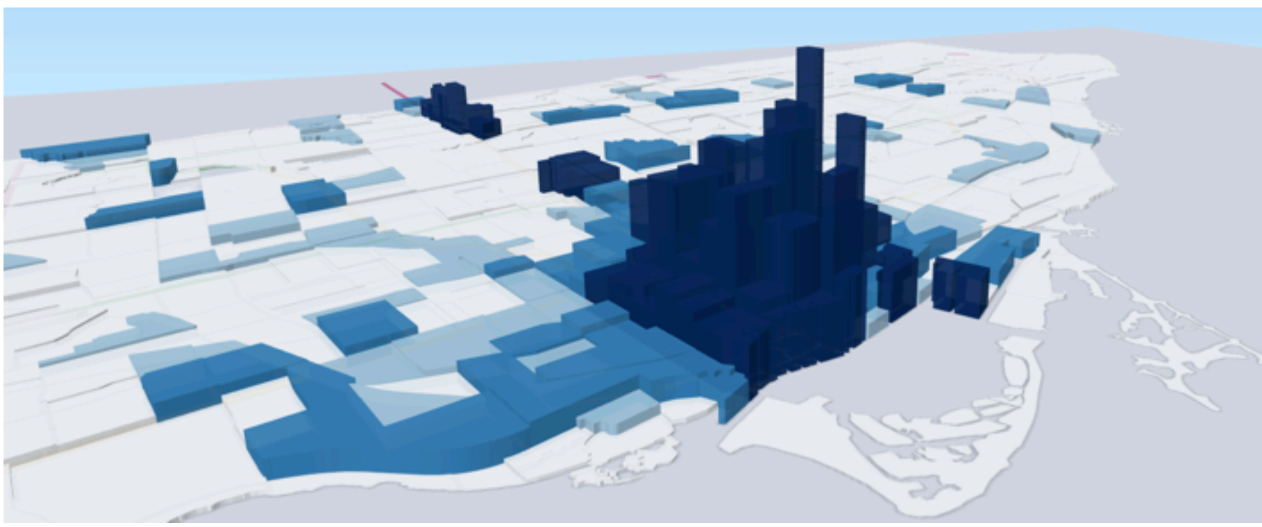


Figure 22. A three dimensional representation of the density of population and employment in 2050.

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

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